FINAL ADDENDUM

TO

THE FINAL EIS

Ewa Marina Community

INCREMENT II

APPENDIX

FINAL ADDENDUM
TO
THE FINAL
ENVIRONMENTAL IMPACT STATEMENT
FOR
INCREMENT II
PROPOSED EWA MARINA COMMUNITY
EWA, OAHU, HAWAII

APPENDIX

July 7, 1986

Prepared by

Dames & Moore
1144 10th Avenue
Honolulu, Hawaii 96816

APPENDICES

1 - SECTION 4.8.3 OF THE FINAL EIS

2 - LITTORAL PROCESSES

3 - WATER QUALITY ANALYSIS

4 - TSUNAMI EFFECTS

5 - MARINE BENTHIC SURVEY

6 - GROUNDWATER STUDY

7 - TRAFFIC STUDY

APPENDIX 1

SECTION 4.8.3 OF THE FINAL EIS

(Alternative Channel Alignments)

4.8.3 Alternative Channel Alignments

Alternative marina entrance channel alignments were developed to examine mitigating effects on surfing. Of the alternatives examined, only Alternative 3 reduces impacts on surfing. All the alignments interrupt public movement along the shore, and have no effect on the archaeological and paleontological impacts anticipated with marina and housing construction. The channel alignments interrupt littoral drift, such that beach profiling, nourishment and sand by-passing may still be required. Alternatives 1 and 2 would have a more significant effect on the beach system than the proposed action in Alternative 3.

Alternative 1 - Channel Through Oneula Beach Park. This alignment cuts the beach park in half resulting in a loss of about 9 acres of park land (See Figure 4-22). The channel and breakwaters would cut through the sand beach having an immediate impact on the beach littoral system. Beach nourishment and sand by-passing may be required to maintain the western half of the beach. Disturbing the beach park was considered unacceptable; flushing evaluations were, therefore, not computed for this alternative.

Alternative 2 - Channel on the east boundary of Oneula Park. This alignment essentially cuts Oneula Park from the existing road access forcing park users to circle around the development to use the park (see Figure 4-23). Down drift erosion to the beach park would probably occur requiring sand nourishment and by-passing. Marina water residence time in basin F in the marina would be increased by 5.6 days.

Alternative 3 - Channel 300 yards west of proposed channel. Alternative 3 is depicted in Figure 4-24. This alignment eliminates any impacts to Oneula Beach Park and significantly reduces adverse effects on the surfing sites. However, the alternative would:

a. increase water residence time in the marina
b. increase the internal travel time within the marina
c. increase land and dredging costs
d. increase automobile traffic bound for the commercial area through the community and park.

Alternative 4 - Eliminate the jetties. This alternative was assessed to reduce the probable impacts of the littoral system. Even though the jetties were eliminated, the entrance channel would effectively trap sand moving westward along the shoreline. Thus, the elimination of the jetties would not reduce littoral drift interruption. Sand trapped in the entrance channel would probably be lost from the littoral system, whereas the jetty would allow some sand to be trapped and by-passed, if necessary, saving the sand within the littoral system. Elimination of the jetties would reduce the impact on one of the identified surfing sites.

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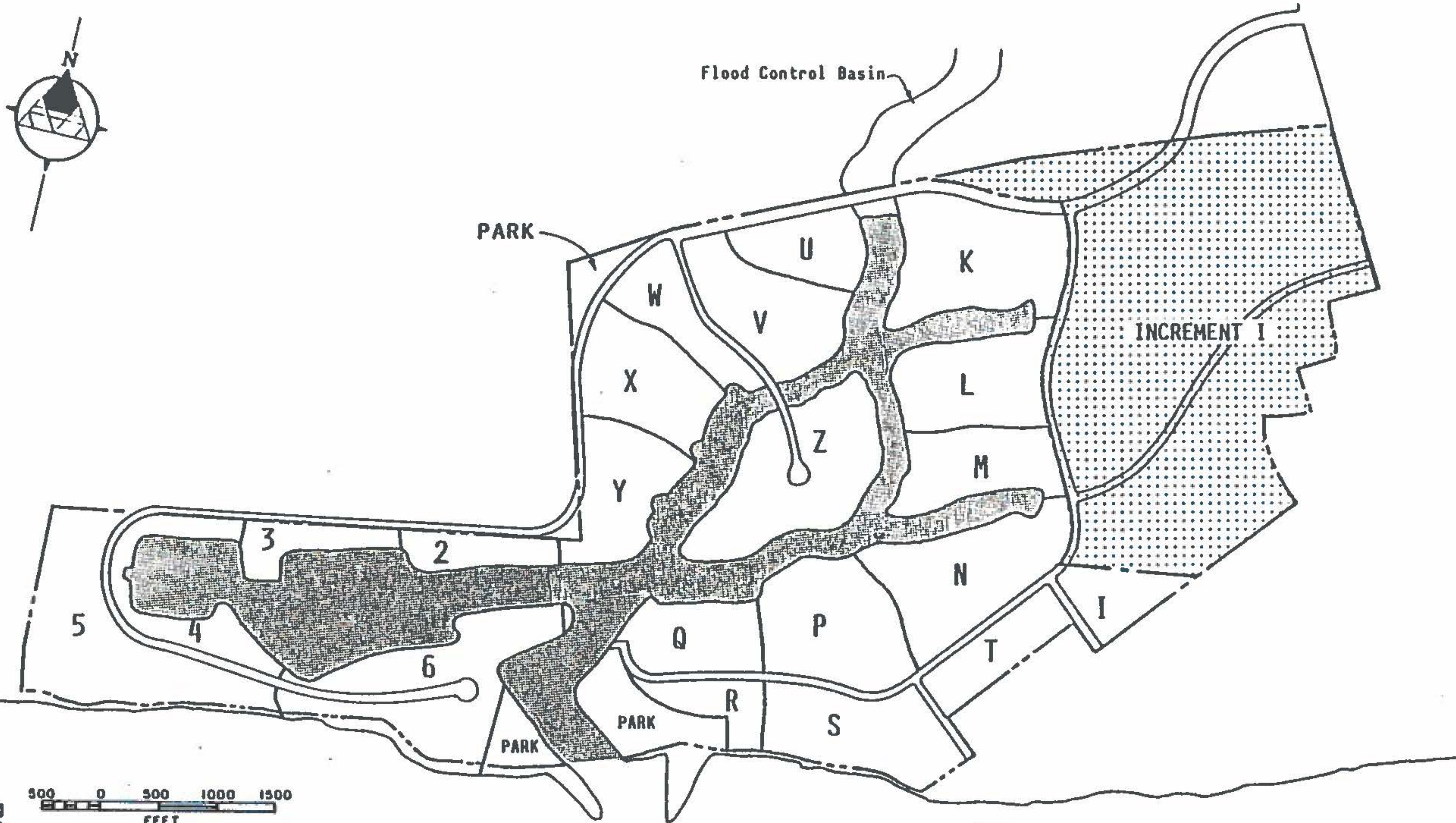


ALTERNATE MARINA CONFIGURATION
ALTERNATIVE NO. 1
EWA MARINA COMMUNITY

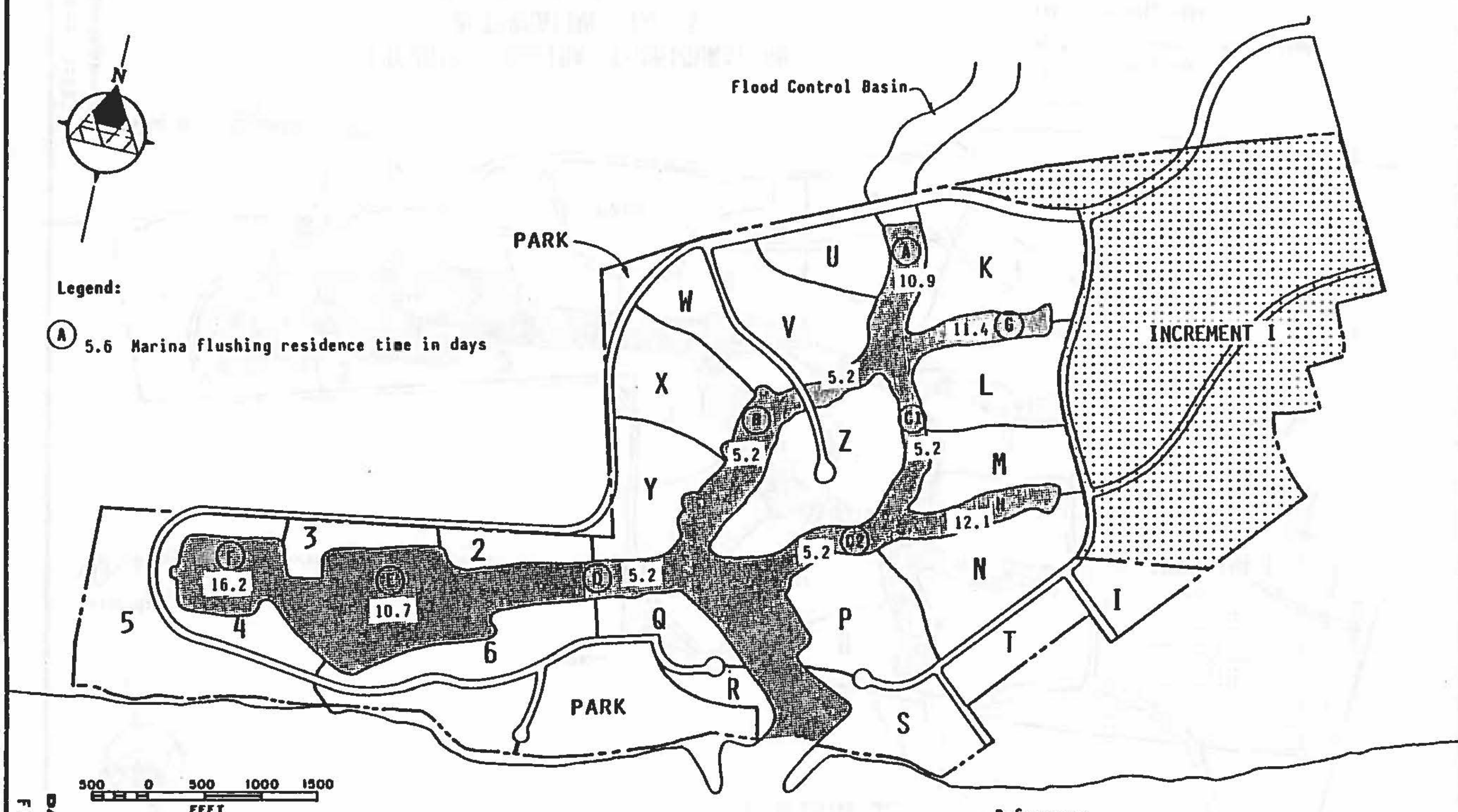
Reference:

MSM & Associates, Inc.
Ewa Marina Community, March 1985

Moffatt & Nichol, 1985

FIGURE 4-22

DAMES & MOORE



ALTERNATE MARINA CONFIGURATION
ALTERNATIVE NO. 2
EWA MARINA COMMUNITY

Reference:

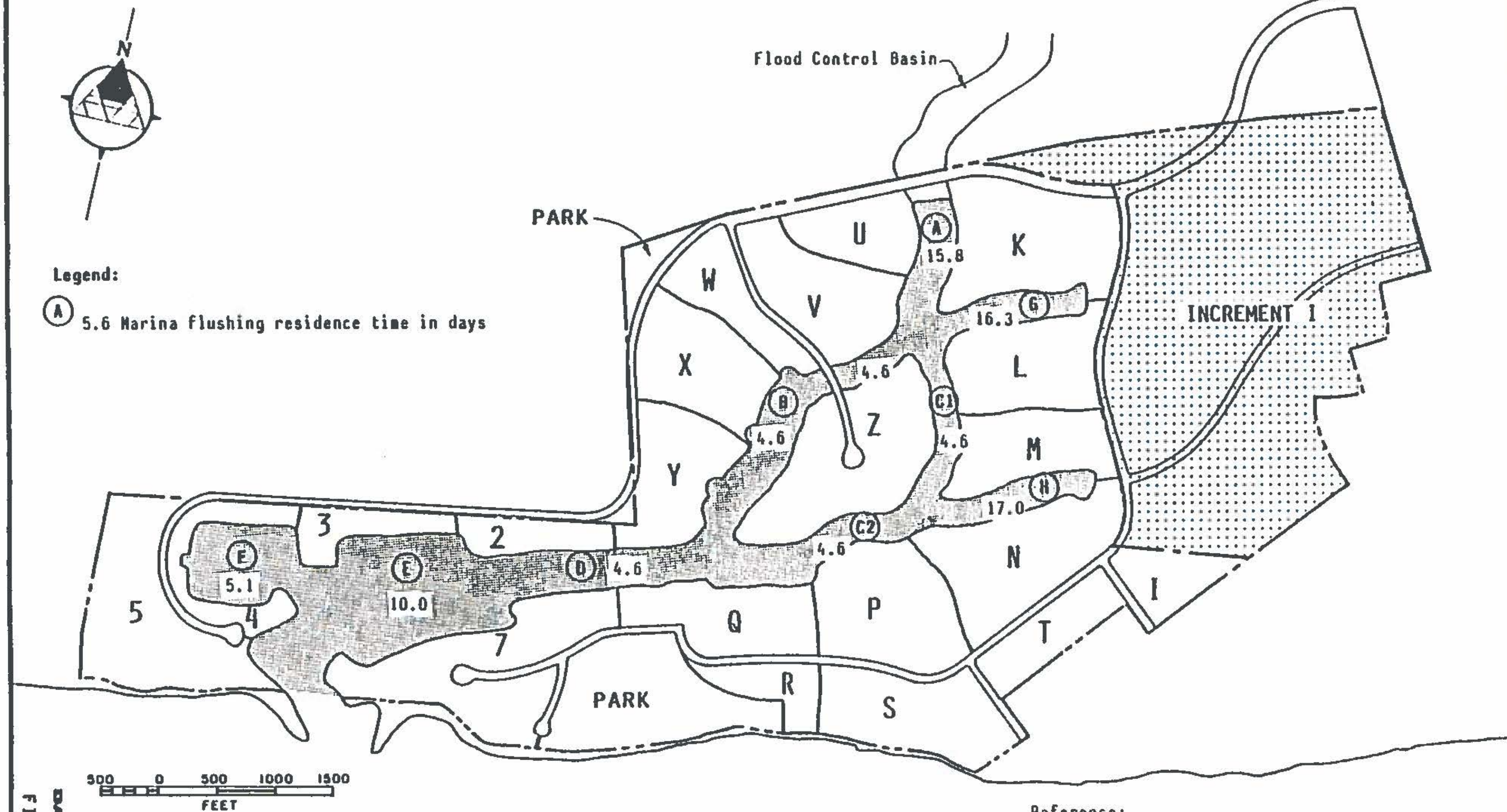
MSM & Associates, Inc.
Ewa Marina Community, March 1985

Moffatt & Nichol, 1985

FIGURE 4-23

DAMES & MOORE

13822-001 SLP 4-03-85



Legend:

(A) 5.6 Marina flushing residence time in days

DAMES & MOORE

FIGURE 4-24

ALTERNATE MARINA CONFIGURATION
ALTERNATIVE NO. 3
EWA MARINA COMMUNITY

Reference:

MSM & Associates, Inc.
Ewa Marina Community, March 1985

Moffatt & Nichol, 1985

APPENDIX 2

LITTORAL PROCESSES

Littoral Processes

for the

Ewa Marina Community Development

Prepared for

M.S.M. & Associates
926 Bethel Street
Honolulu, Hawaii 96813

Prepared by

Moffatt & Nichol, Engineers
250 W. Wardlow Road
Long Beach, CA 90807

March 20, 1986

Introduction

The proposed Ewa Marina would communicate with the ocean through a 400-foot wide entrance channel. Two alternative entrance locations are proposed; one alternative is located at the rocky headland at the west end of Oneula Beach, the second alternative is located approximately 1,200 feet west of the headland. The entrance channel would extend to the -20 foot MLLW contour. Construction of an entrance channel may affect beach processes which include wave climate, water currents, and littoral transport.

The purpose of this study is to develop an understanding of the coastal processes at the project site and discuss impacts on the beach system due to a marina entrance at two alternative locations.

The scope of this study includes: 1) investigate the beach system in the area based on data available; 2) evaluate marina entrance locations for impacts on beach processes. The study was limited to available data.

Littoral Processes

The coastline between Pearl Harbor and Barbers Point comprises a series of small pocket beaches separated by reaches of beachrock along the shoreline. A coral-algae reef slopes gently offshore to deeper water. See Figures 1 and 2 for site plan and beach profiles. This reef is not completely similar to the barrier reefs found in Kaneohe or Ala Moana because it drops more rapidly into deep water. The beaches comprise a medium grain size, calcareous sand, are typically 100 feet wide, and have an elevation of about 9 to 10 feet above mean sea level. Small sand dunes and beachrock are found along the shoreline. The coral-algae reef is interspersed with shallow, sand-filled channels and pockets.

Moberly and Chamberlain (1964) suggest that appreciable onshore and offshore transport occurs on barrier reefs and longshore transport may be of secondary importance. The beach and sand channel are a reservoir/

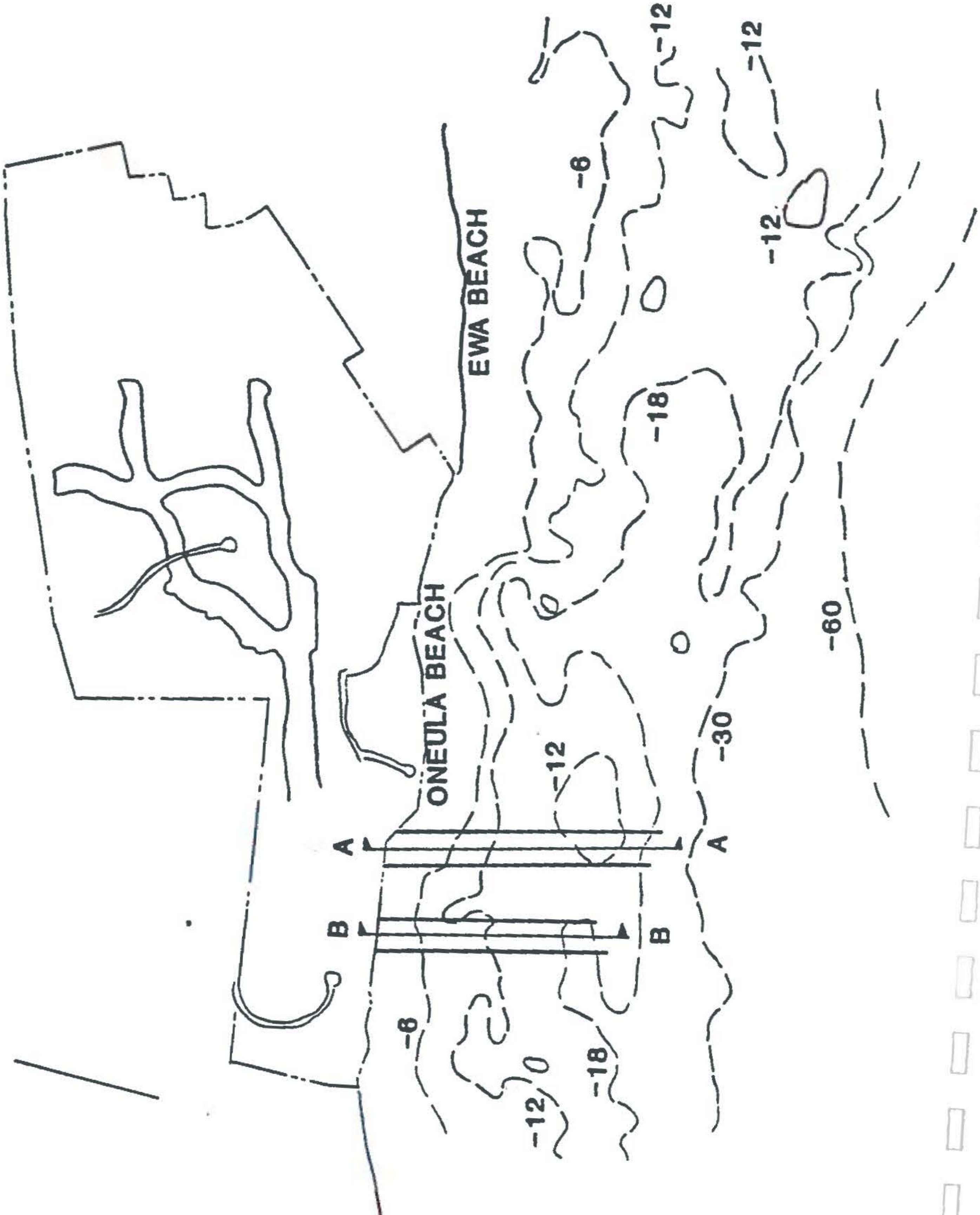
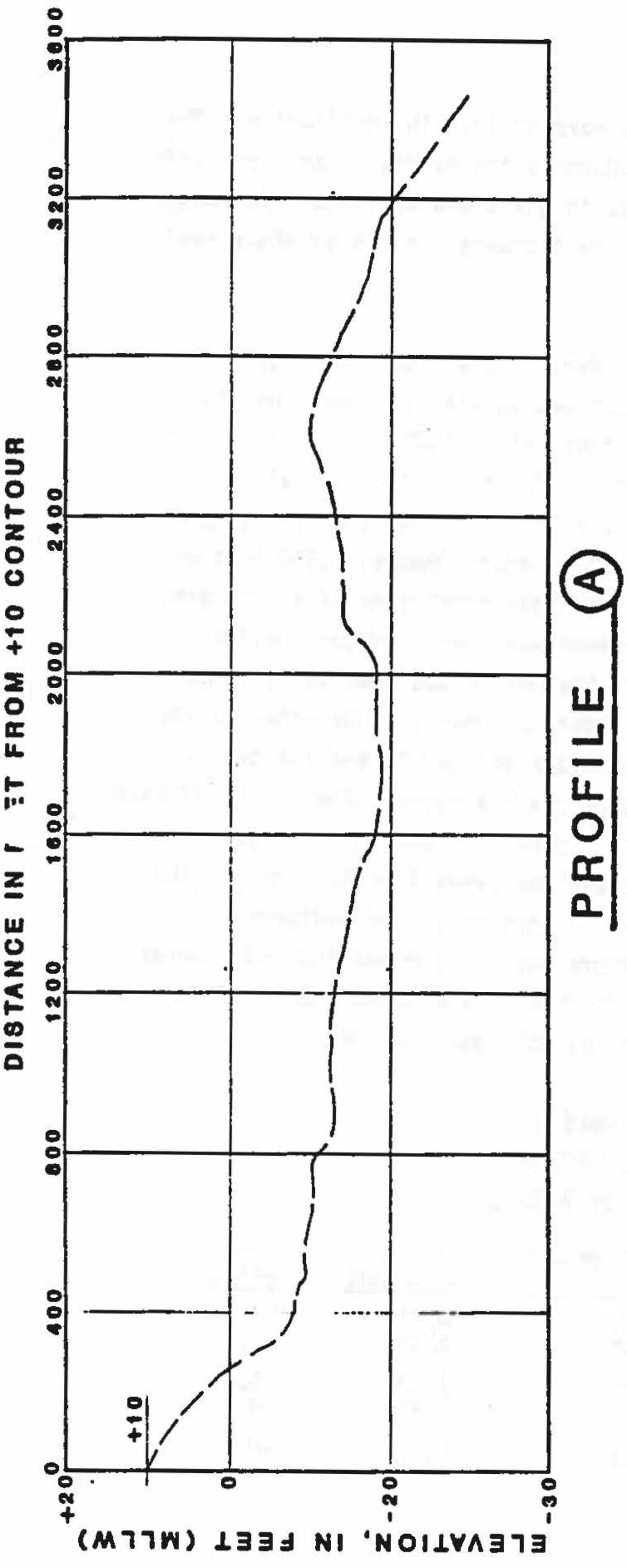
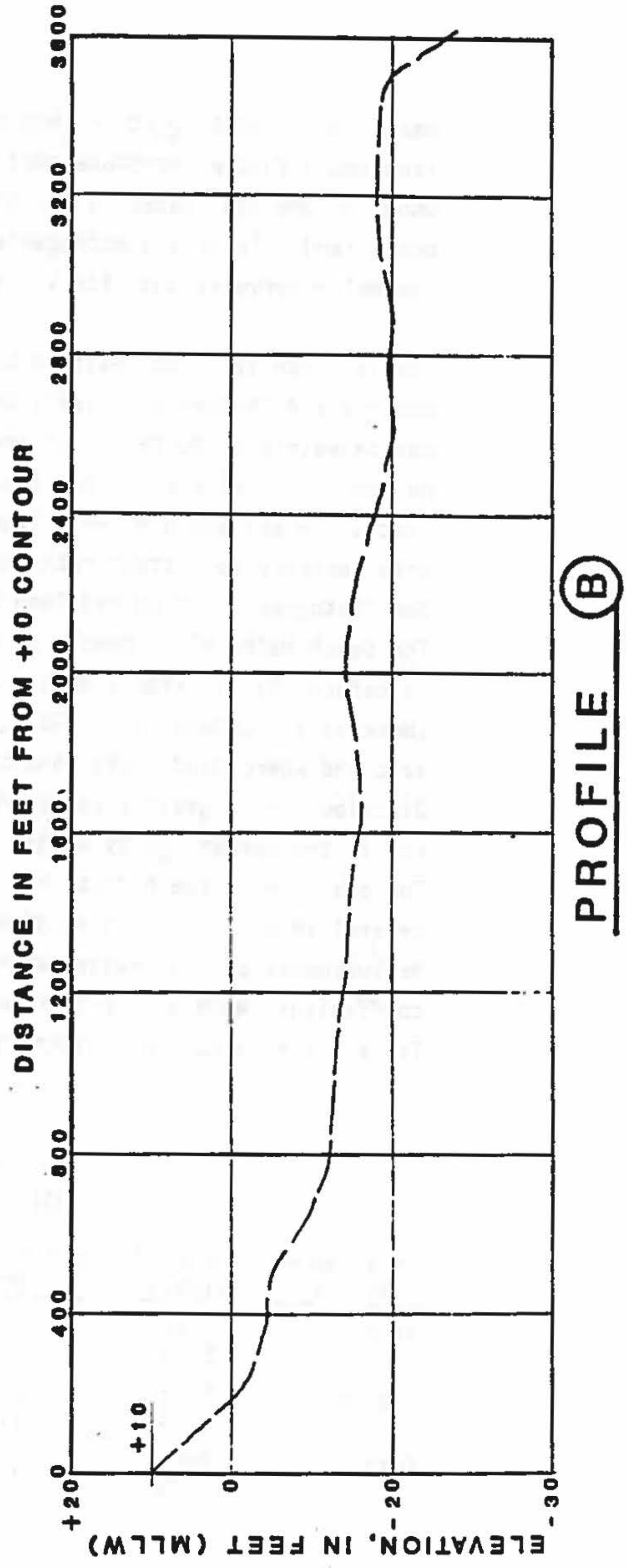


FIGURE 1.





PROFILES — EWA/ONEULA SHORELINE

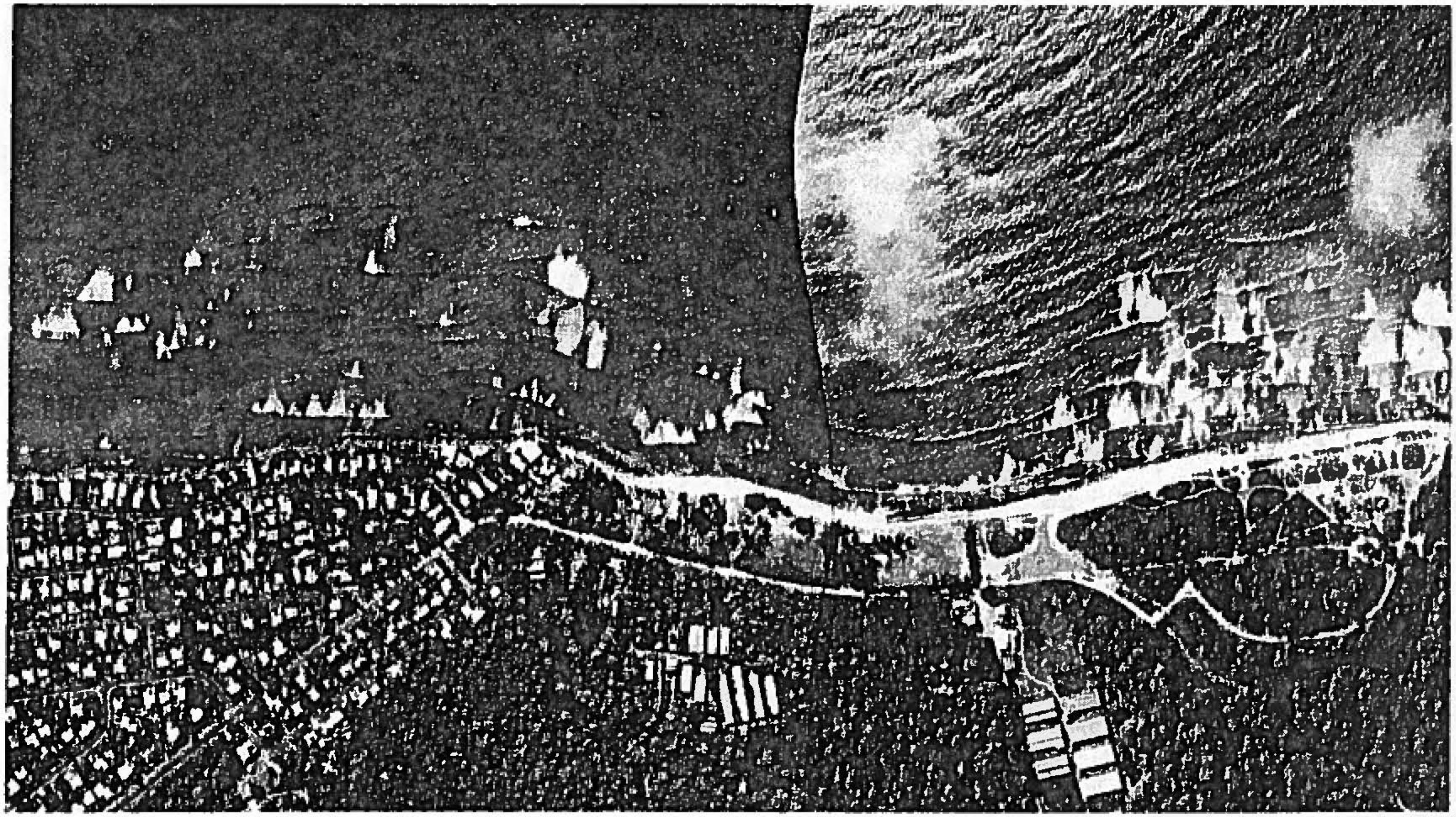
FIGURE 2.

beach system that together remains more or less in equilibrium. The sand found in the nearshore reef channels represents a sand reservoir whose volume fluctuates in response to waves and currents. Increases in beach sand volumes are accompanied by decreases in the offshore reef channel reservoirs and vice versa.

Oneula Beach is on the eastern boundary of the site (see Figure 1). Moberly and Chamberlain (1964) described Oneula as a small beach, approximately 3,000 feet long and containing 36,000 cubic yards of sand. Review of aerial photographs (Hwang, 1981) indicates that along Oneula Beach, a sandy beach extends from a rock outcrop east of the project site boundary to another rocky headland approximately 3,300 feet west. See Photograph 1 rocky headland at extreme right side of photograph. The beach material at Oneula is a moderately well-sorted, medium calcareous sand. From a survey of beaches on the Hawaiian Islands (Moberly and Chamberlain, 1964), Figure 3 shows the character of the sand and where sand, coral and beachrock existed during the survey. Distribution of grain size is shown by a histogram. The height of each bar is the percentage by weight of sediment in each unit of grain size. The position of the highest bar shows the overall grain size and the general shape of the figure shows the sorting of the sediment. Measurements of grain-size parameters such as the sorting and skewness coefficients were also presented in Moberly and Chamberlain (1964). See Table 1 for measurements taken in May 1962 and May 1963.

TABLE 1
EWA BEACH
GRAIN SIZE PARAMETERS

Location of Sample	Date of Sample	Median Diameter (mm)	Sorting Coefficient	Skewness Coefficient
Berm	5/62	0.71	0.68	0.04
	5/63	0.42	0.38	-0.23
Sea Level	5/62	0.66	0.60	0.0
	5/63	1.27	0.85	0.05
Offshore	5/62	0.54	0.40	-0.50
	5/63	0.35	2.05	0.49

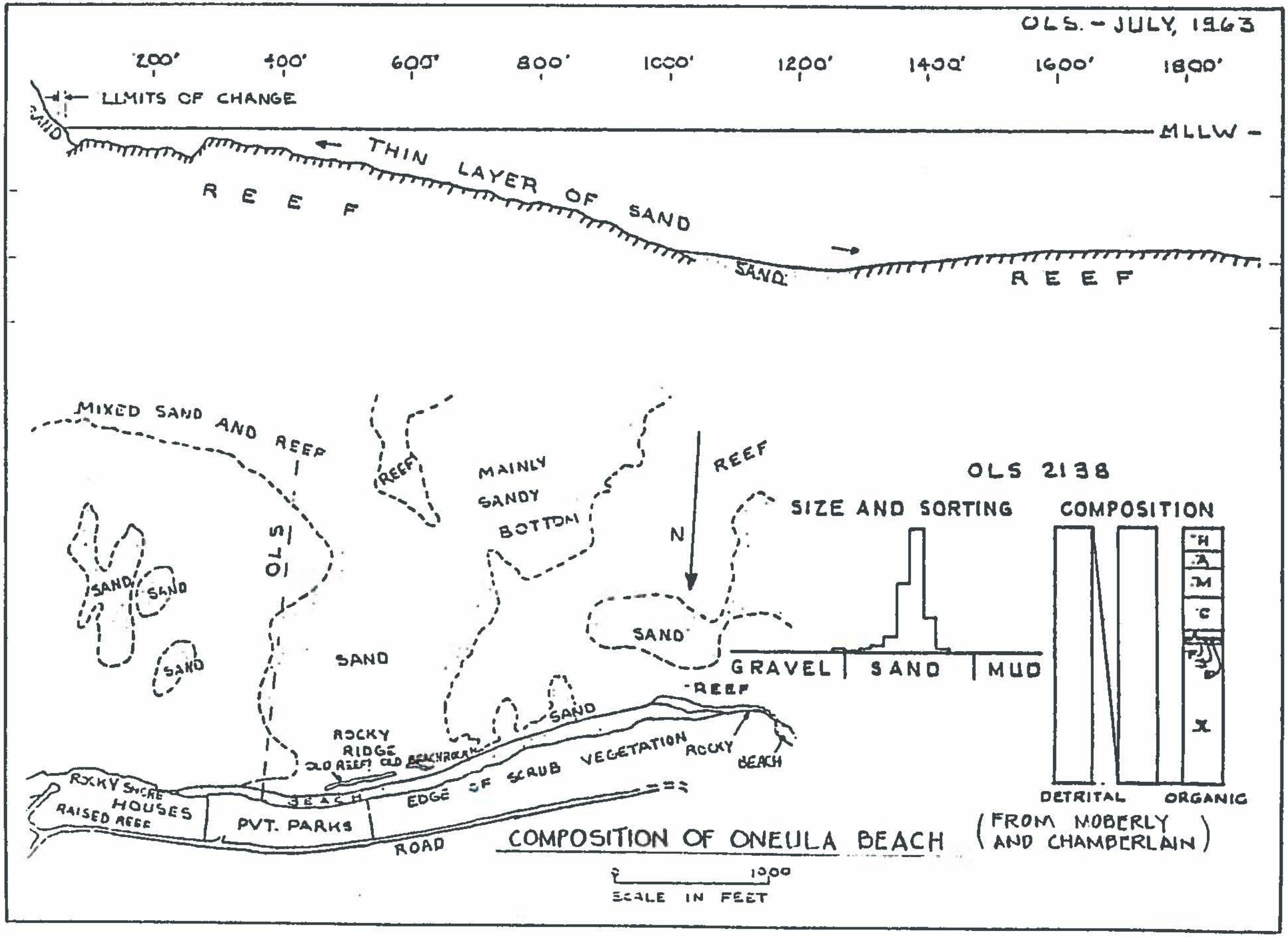


ONEULA BEACH

REFERENCE: HWANG (1981)

NOTE: ROCKY HEADLAND IS AT
EXTREME RIGHT OF PHOTOGRAPH

PHOTOGRAPH 1



COMPOSITION OF ONEULA BEACH

FIGURE 3.

From Figure 3, a large sand channel is located directly offshore from Oneula Beach. The littoral processes in the area along Oneula Beach appears to be a cellular system. The shoreline is confined between two mild headlands and the primary mode of transport is an onshore/offshore transport. A surface geology map was prepared by Noda (1985) for a proposed entrance channel located at the rocky point at the west end of Oneula Beach Park. See Figure 4. The survey indicated two sand pockets offshore with sand thicknesses of less than 2 feet. Most of the offshore reef was coral bottom or a sand and coral bottom that was characterized by scattered pockets of thin layers of sand on a flat coral bottom or a coral bottom with mild relief.

Aerial photograghs indicate that the shoreline from the rocky promontory along Oneula Beach Park west to Nimitz Beach is mostly rocky with little to no sand. No large sand reservoirs have been documented offshore this reach of shoreline.

Nimitz Beach is located to the west of Oneula Beach. It was artificially constructed and consists of alternating reaches of sand and rock (Hwang, 1981). Analysis of historical aerial photographs and changes in the vegetation line by Hwang (1981) indicated that Nimitz Beach has been accreting. However, documentation of any offshore sand reservoirs was not available.

Littoral processes are influenced by the waves and currents in the region. Wave climate in Hawaii was described by Moberly and Chamberlain (1964) and Marine Advisers (1964). The site is exposed to Kona storm waves, southern swells and northeast trade waves. Kona storm waves are generated by winds associated with local fronts or Hawaiian lows of extratropical origin. Kona storm waves approach the Hawaiian Islands from directions between southeast and west, larger waves are usually from the southwest. Typically, wave periods range from 8 to 10 seconds and wave heights range from 10 to 15 feet. Southern swells arriving in the Hawaiian Islands are typically long-period waves ranging from 14 to 22 seconds and wave heights ranging from 1 to 4 feet in deep water. The direction of approach is from the southern quadrant. Northeast trade

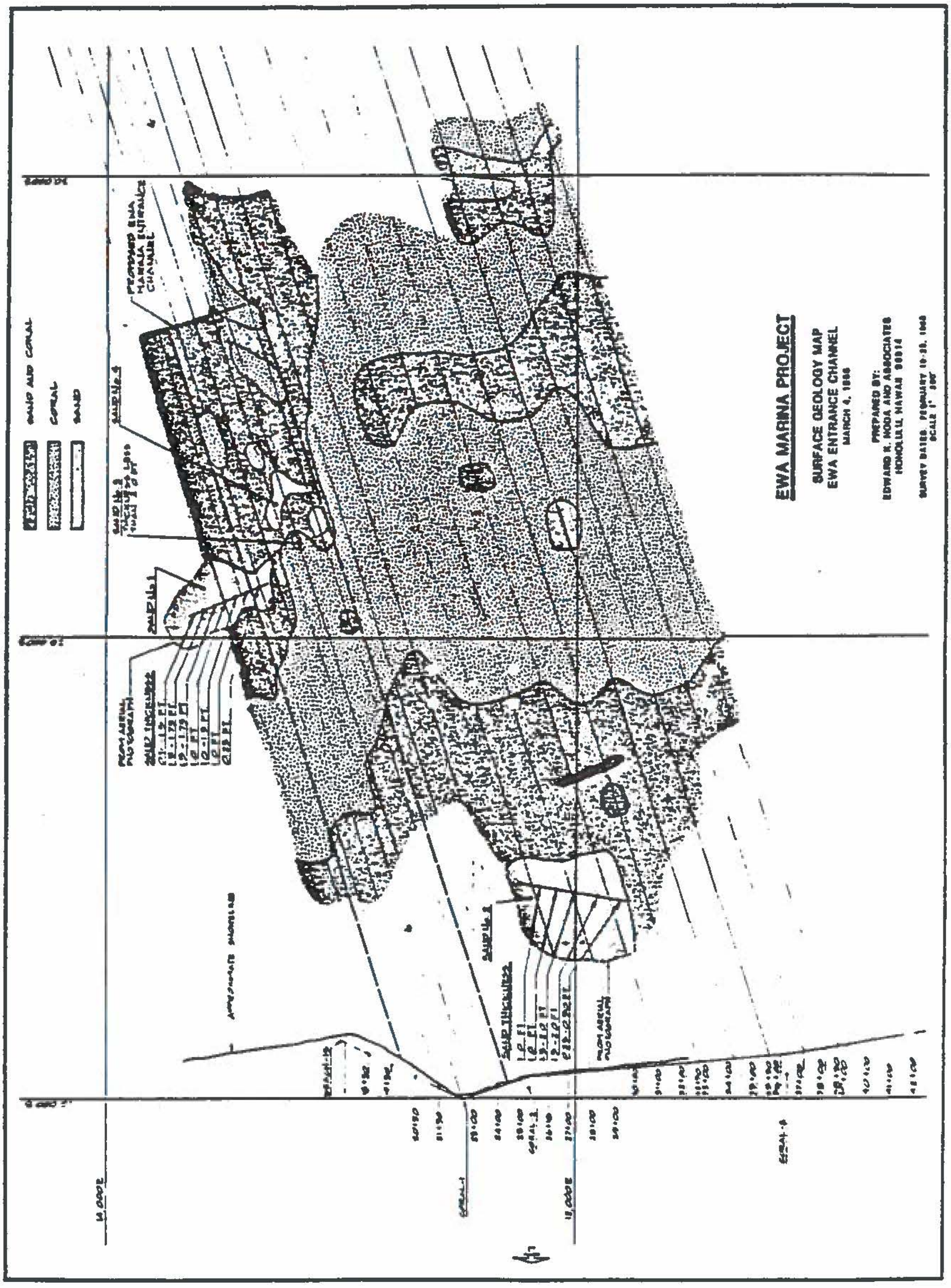

EWA MARINA PROJECT
SURFACE GEOLOGY MAP
EWA ENTRANCE CHANNEL

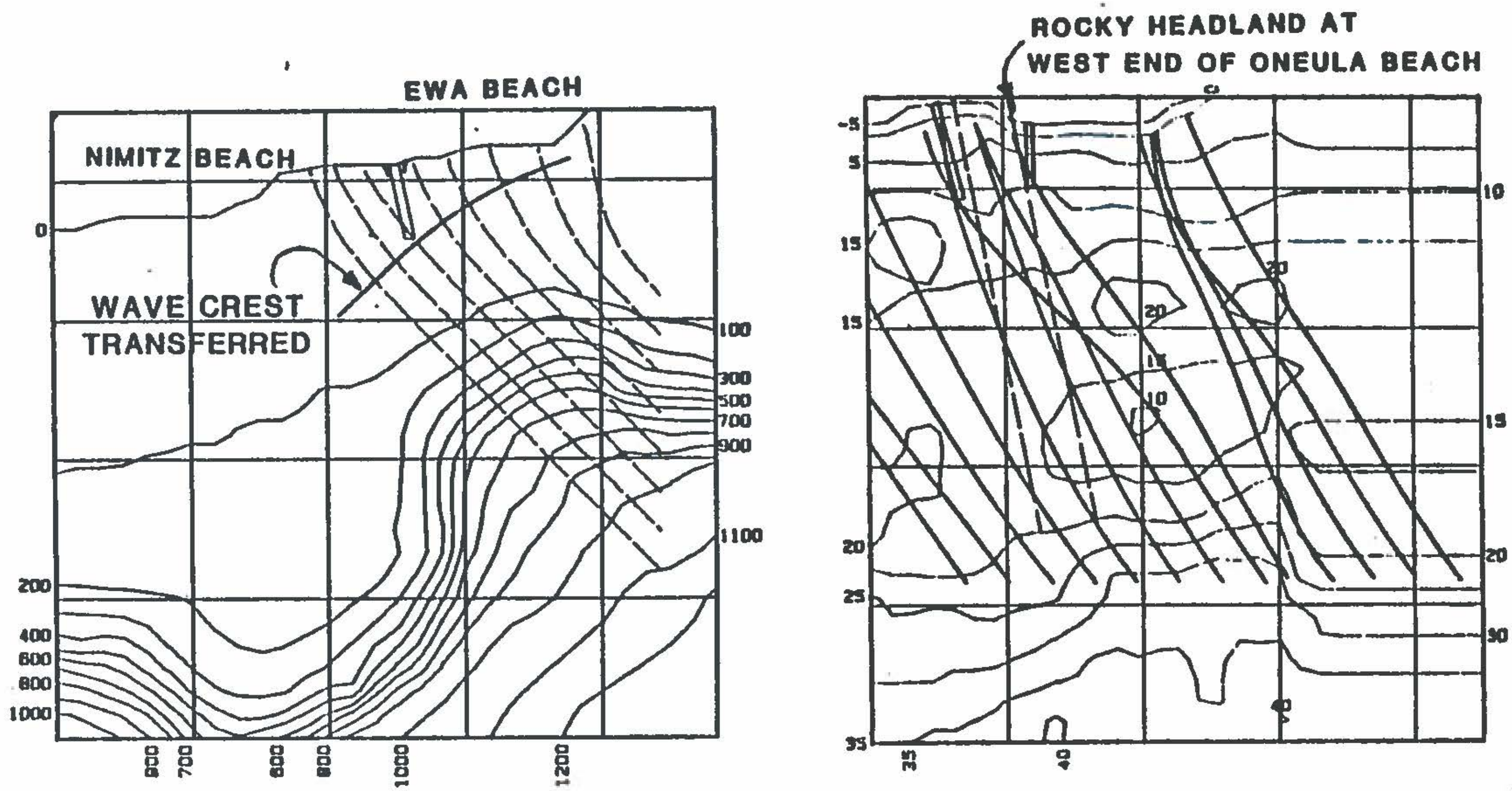
FIGURE 4

waves are generated by trade winds over long fetches of open ocean. The trade waves are typically between 4- to 12-feet high and wave periods range from 5 to 8 seconds. The Ewa shoreline is exposed to waves that refract around Diamond Head and approach shore.

Due to the complex bathymetry of the reef, a wave refraction analysis was performed to determine directions of predominant wave attack relative to shoreline orientation. Wave refraction diagrams were prepared by using bathymetry from NOAA Chart No. 19362 and transferring wave crest positions to a bathymetry taken from a survey by M&E Pacific (1984). Wave refraction computations were performed using a numerical model employing linear wave theory described by Headland (1983). The entrance channel shown on the diagrams is located at the rocky headland at the west end of Oneula Beach; the alternative entrance channel located near the west project boundary is at the extreme left side of the nearshore drawings. Analysis suggests a convergence of wave energy on the west side of the point where Oneula Beach is generally observed to terminate. See Figures 5 through 23. Aerial photographs also indicate a convergence of wave energy (see Photographs 2 through 4. There is a divergence of wave energy along the reach of shoreline from the headland west to Nimitz Beach. Figures 7 through 13 show the wave refraction diagrams for the nearshore bathymetry for directions azimuth 157 and 180 degrees and wave periods of 8 to 16 seconds.

Seasonal fluctuations of the beach and sand reservoirs are very pronounced in Hawaii. Beach volumes were tabulated for selected beaches on Oahu from 1962 to 1972 (Campbell, 1972). Volumes at Ewa Beach fluctuated as much as 65,000 cubic yards between June 1962 and January 1963. During the winter, the northeast trade winds weaken and southwesterly winds (and Kona storm waves) appear. During the summer, strong northeast trades return. In addition to the large volumes of sand transported onshore and offshore, some sand is transported alongshore by currents (Moberly and Chamberlain, 1964).

Current data for Oahu waters have been compiled in an atlas by Bathen (1978). The net current at any time and place can be taken as the sum



DEEPWATER

DEPTH CONTOURS
IN FEET

NEARSHORE

BATHYMETRY REFERENCE:

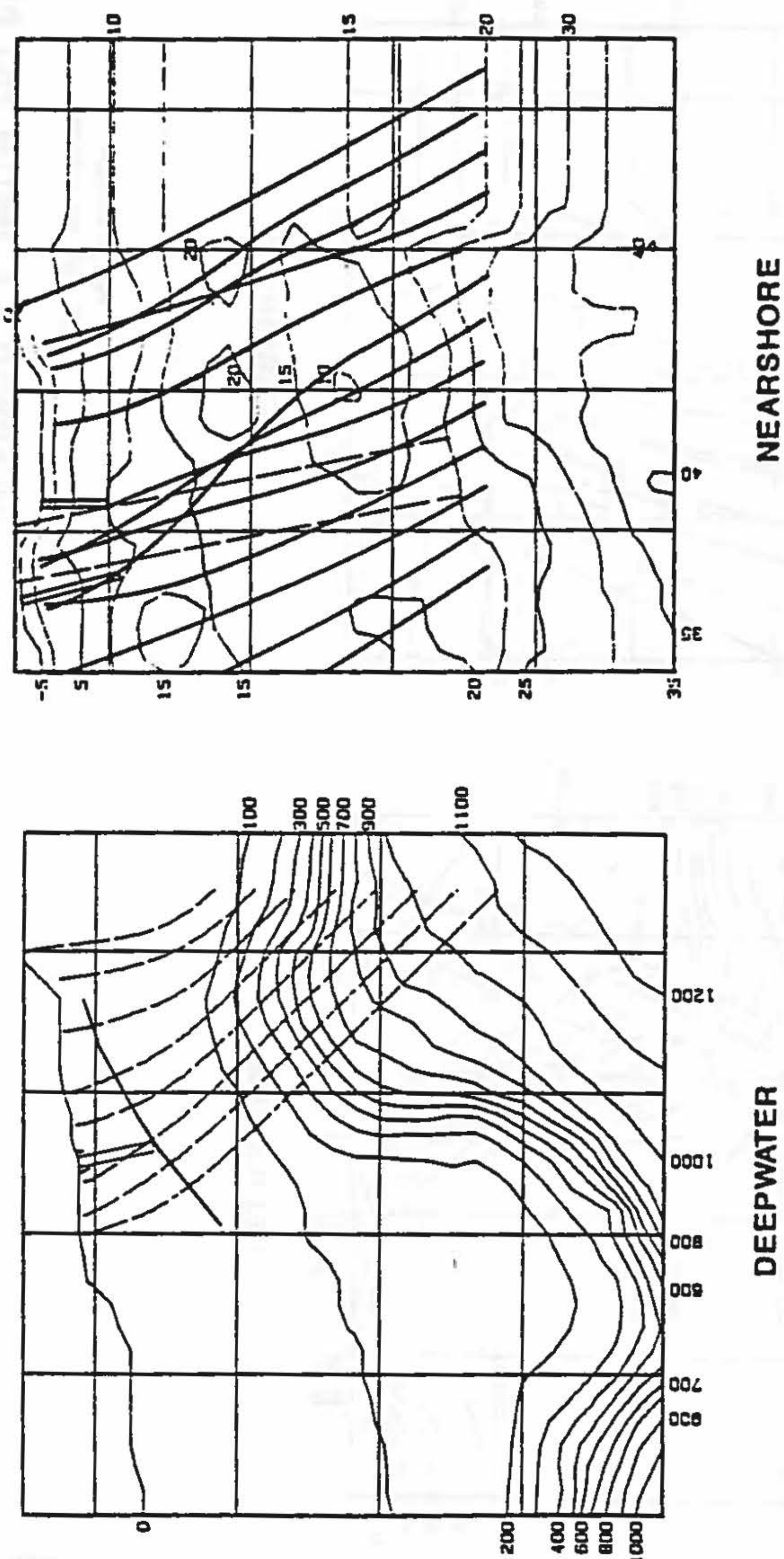
DEEPWATER - NOAA CHART 19362

NEARSHORE - SURVEY BY M & E PACIFIC INC. 1984

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 135 DEG.
PERIOD 6 SEC.

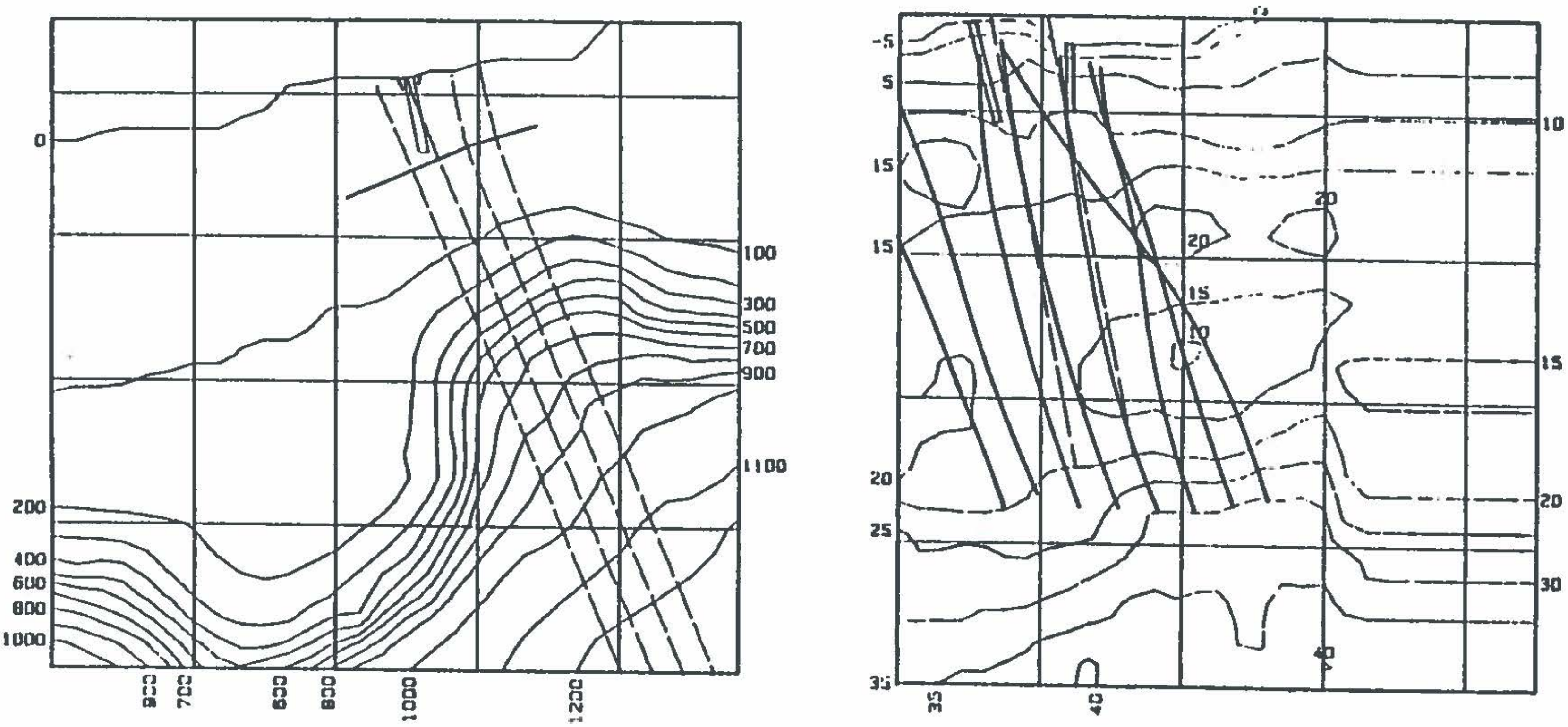
FIGURE 5



EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 135 DEG.
PERIOD 8 SEC.

FIGURE 6

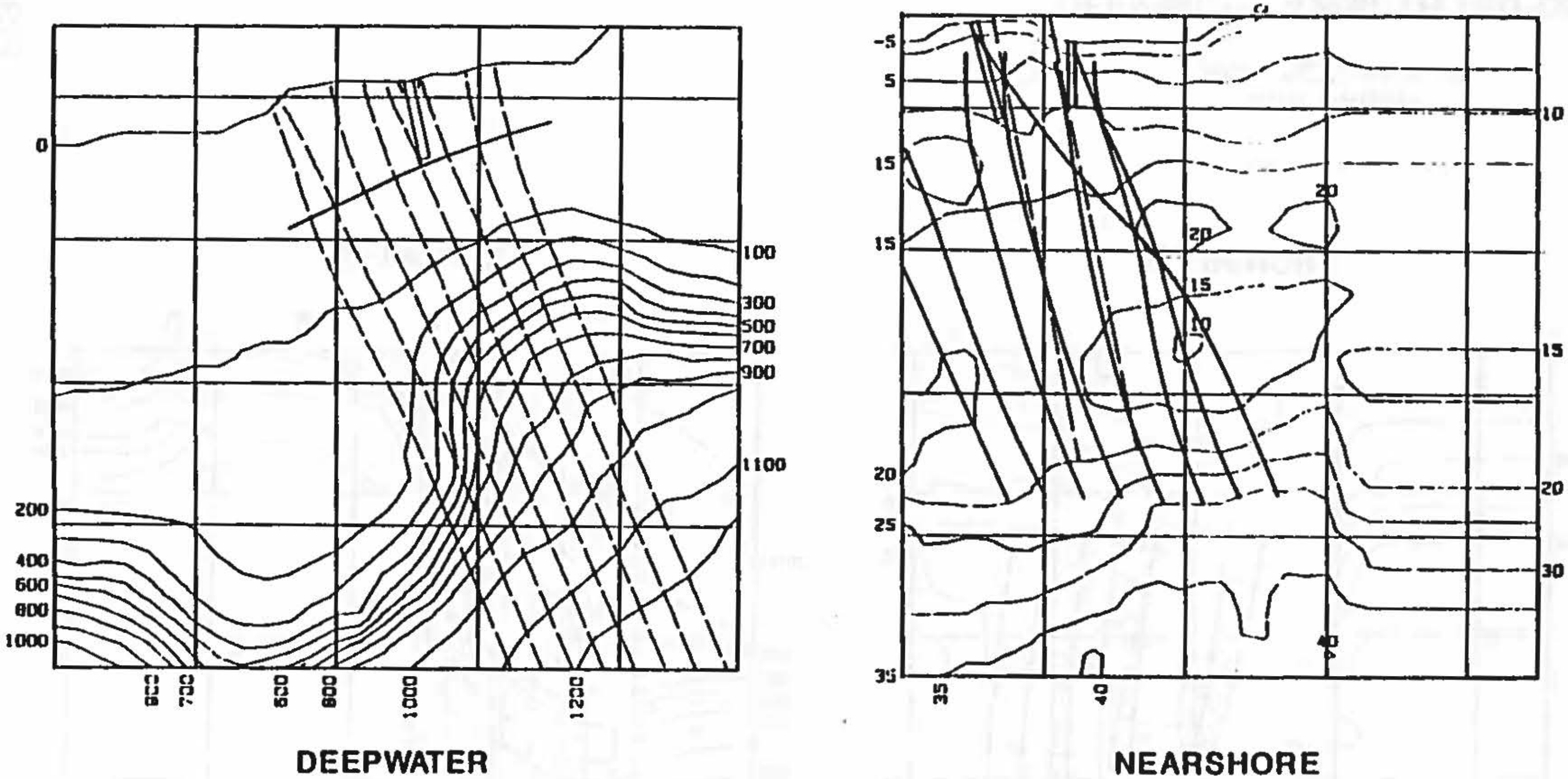


DEEPWATER NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 157 DEG.
PERIOD 8 SEC.

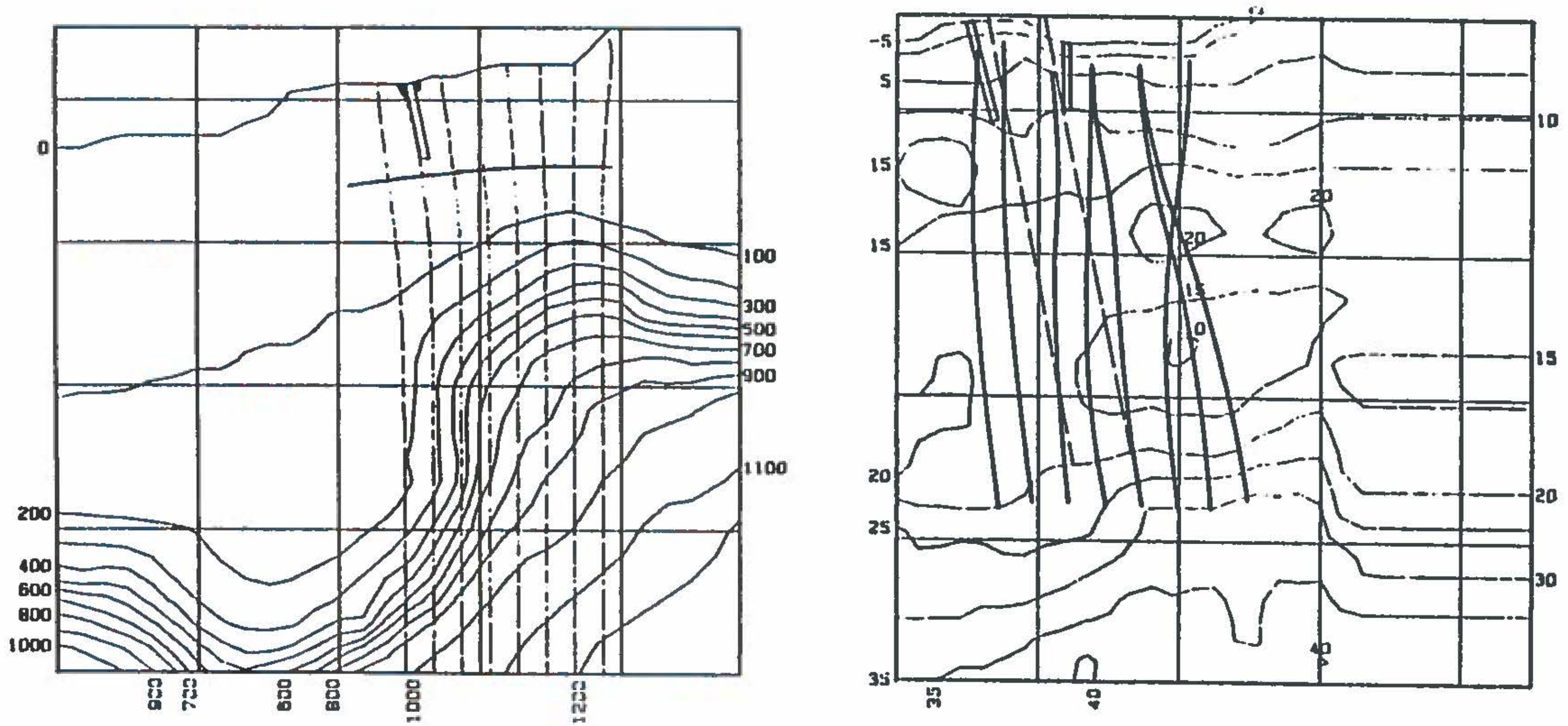
FIGURE 7



EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 157 DEG.
PERIOD 10 SEC.

FIGURE 8

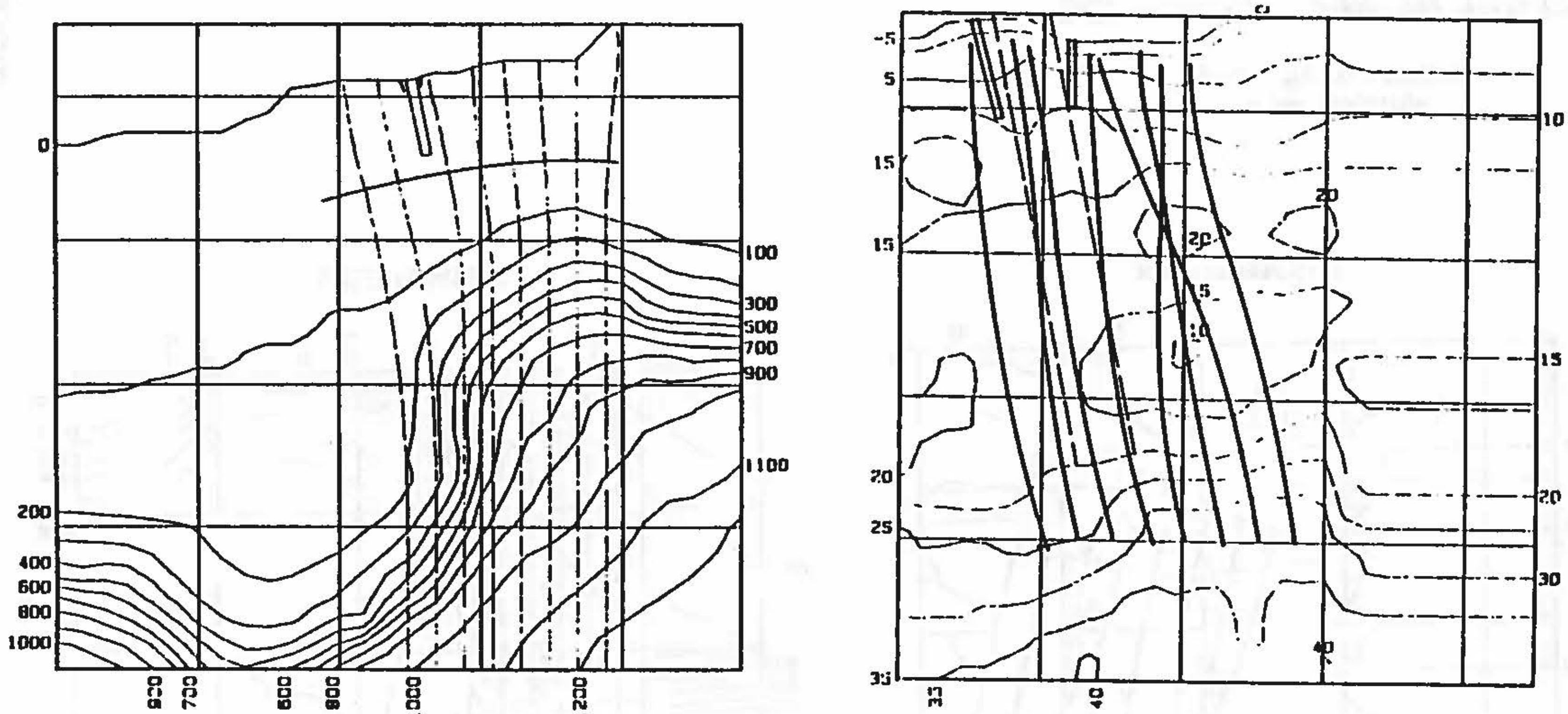


DEEPWATER   NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 180 DEG.
PERIOD 8 SEC.

FIGURE 9

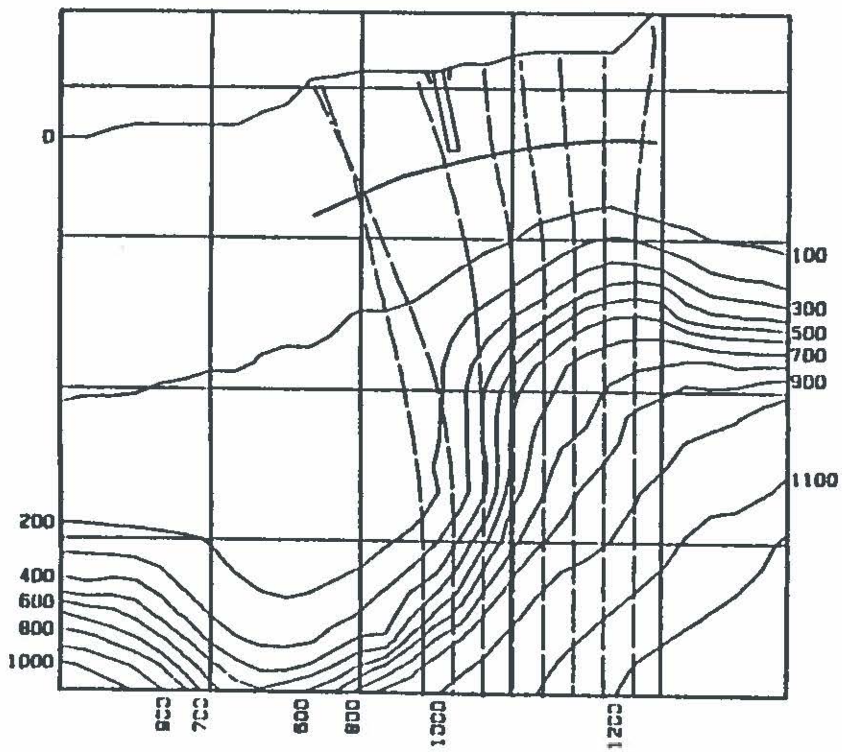


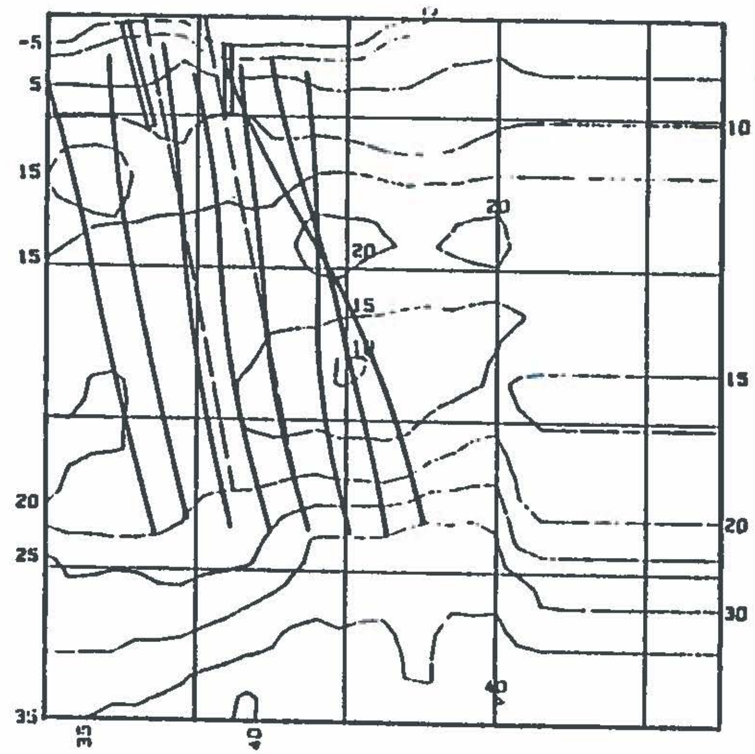
DEEPWATER **NEARSHORE**

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 180 DEG.
PERIOD 10 SEC.

FIGURE 10

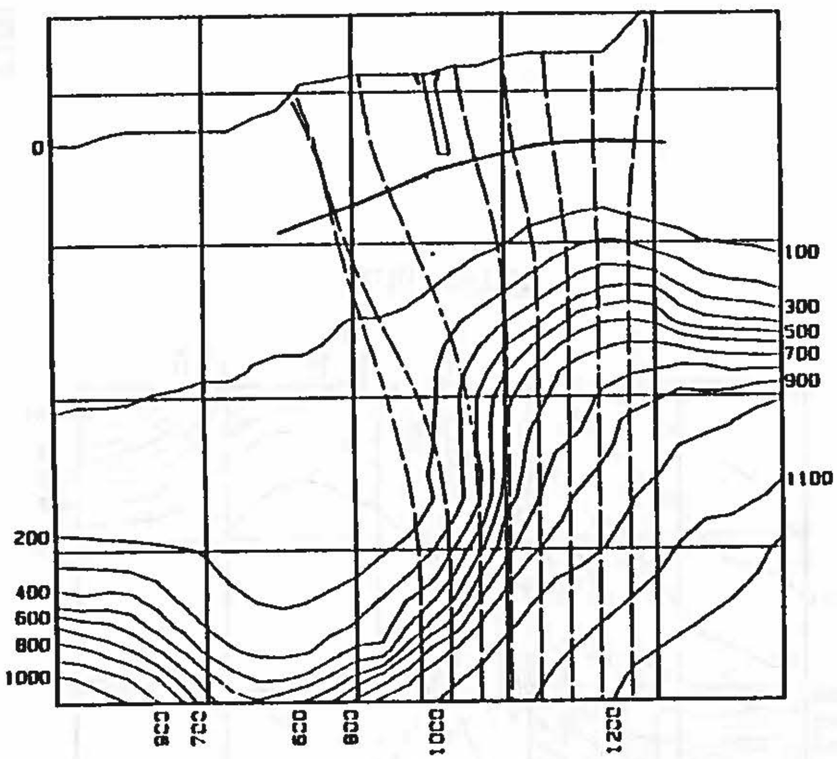




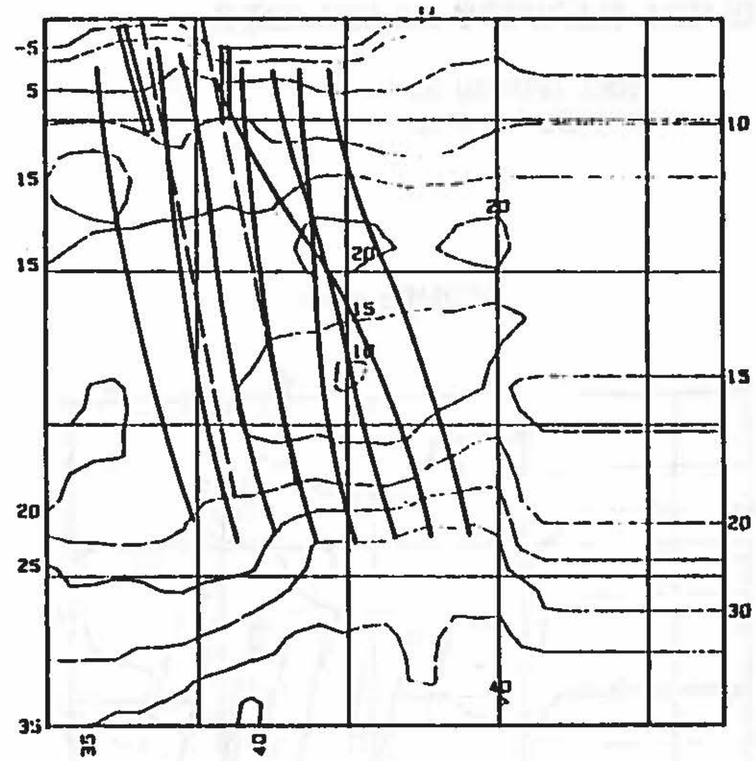
EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 180 DEG.
PERIOD 12 SEC.

FIGURE 11



DEEPWATER

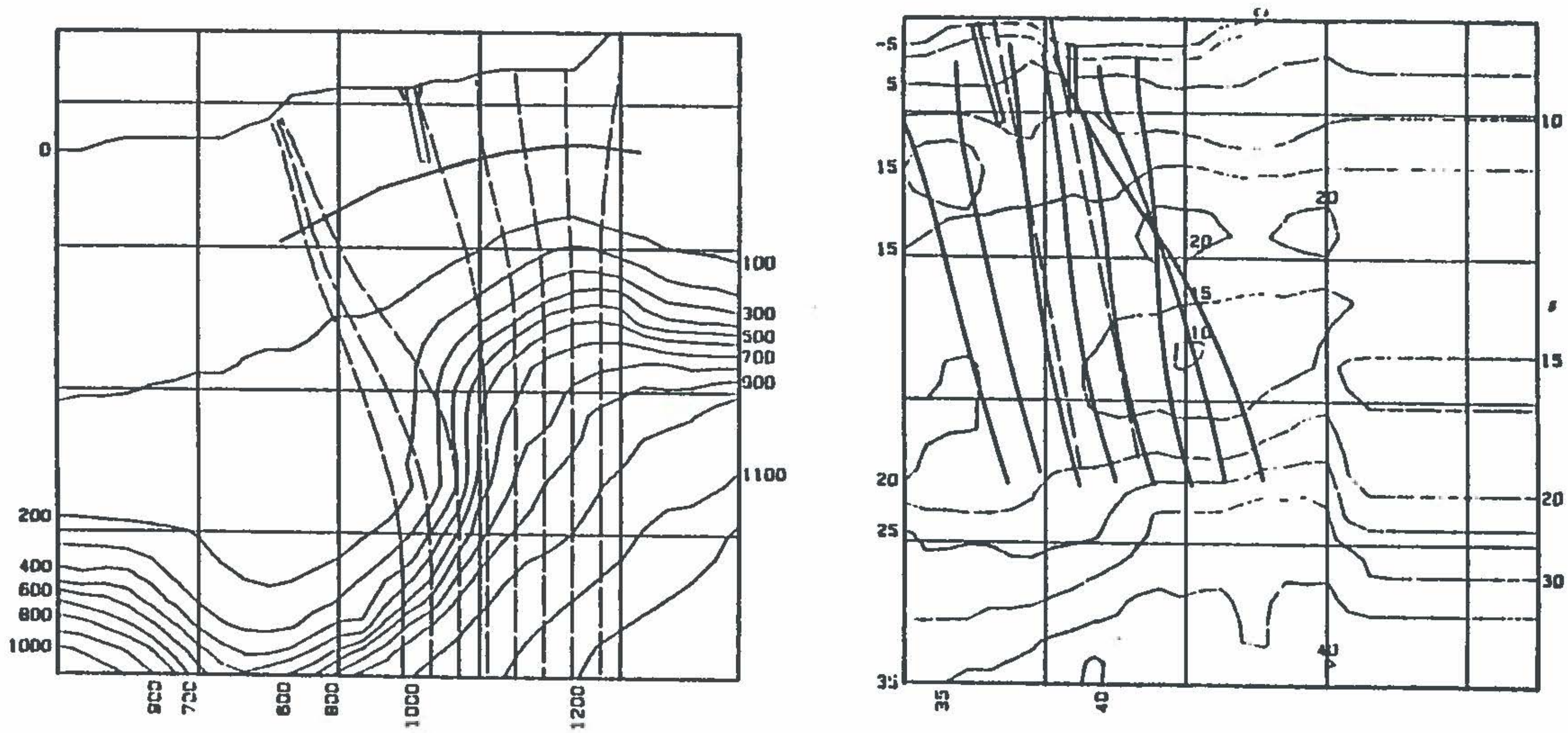


NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 180 DEG.
PERIOD 14 SEC.

FIGURE 12



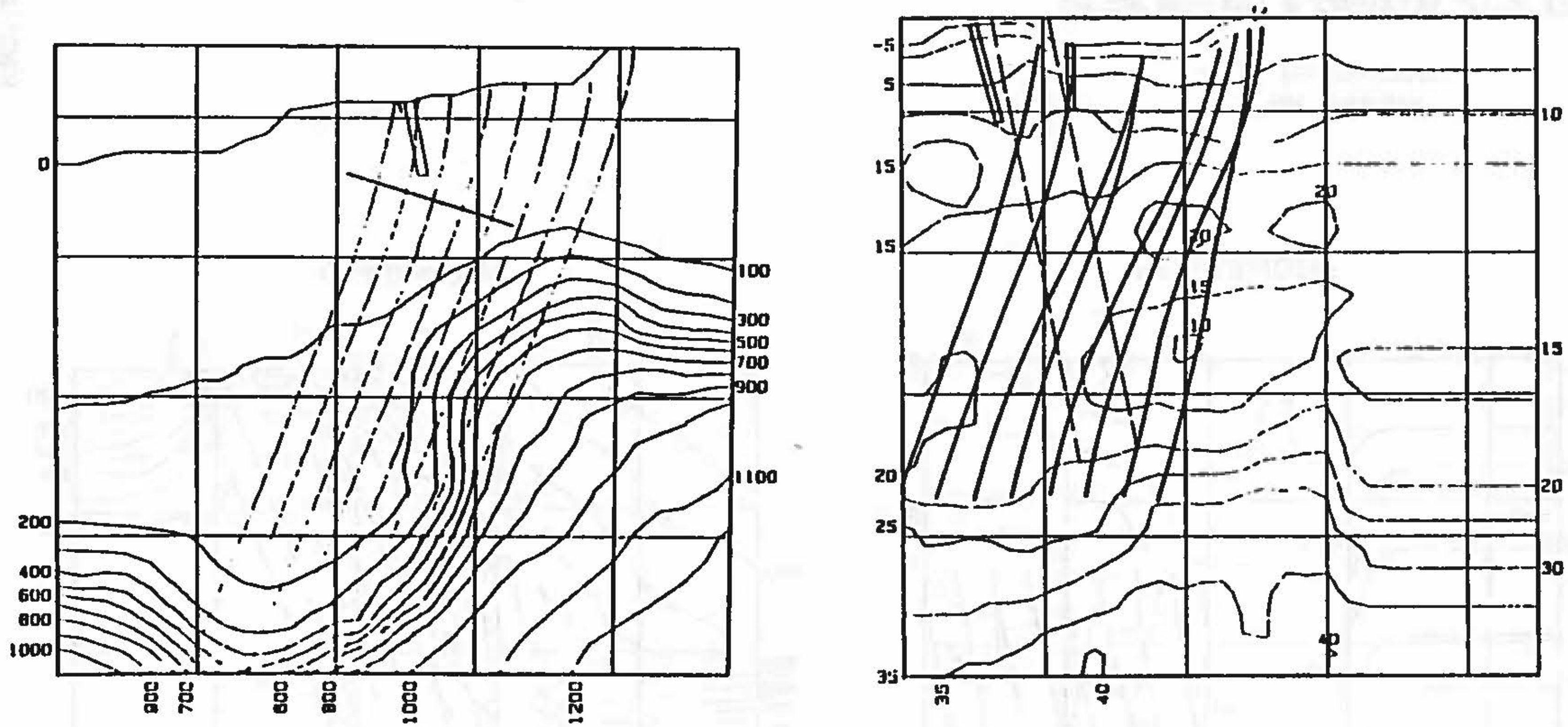
DEEPWATER

NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 180 DEG.
PERIOD 16 SEC.

FIGURE 13



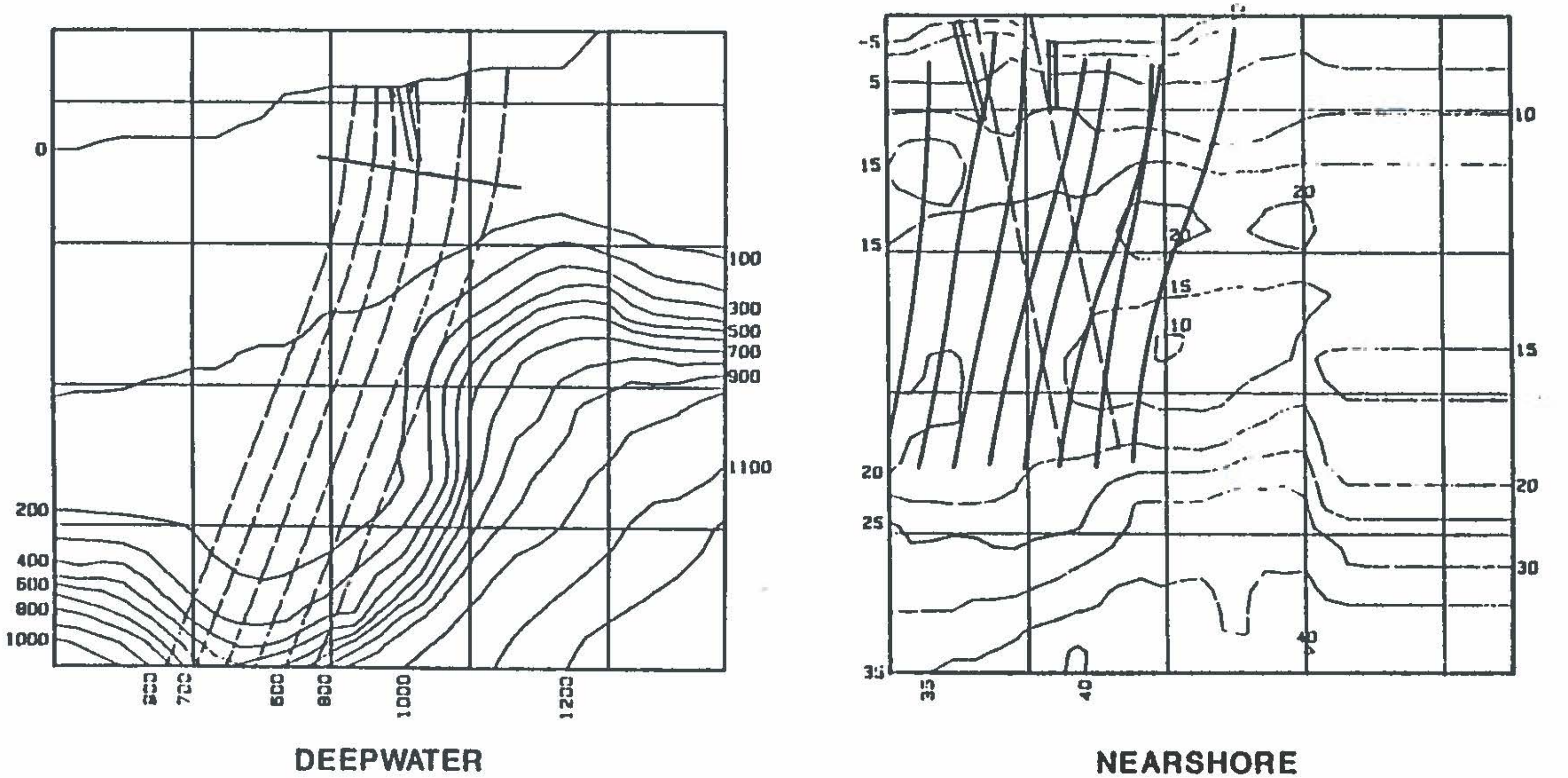
DEEPWATER

NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 202 DEG.
PERIOD 6 SEC.

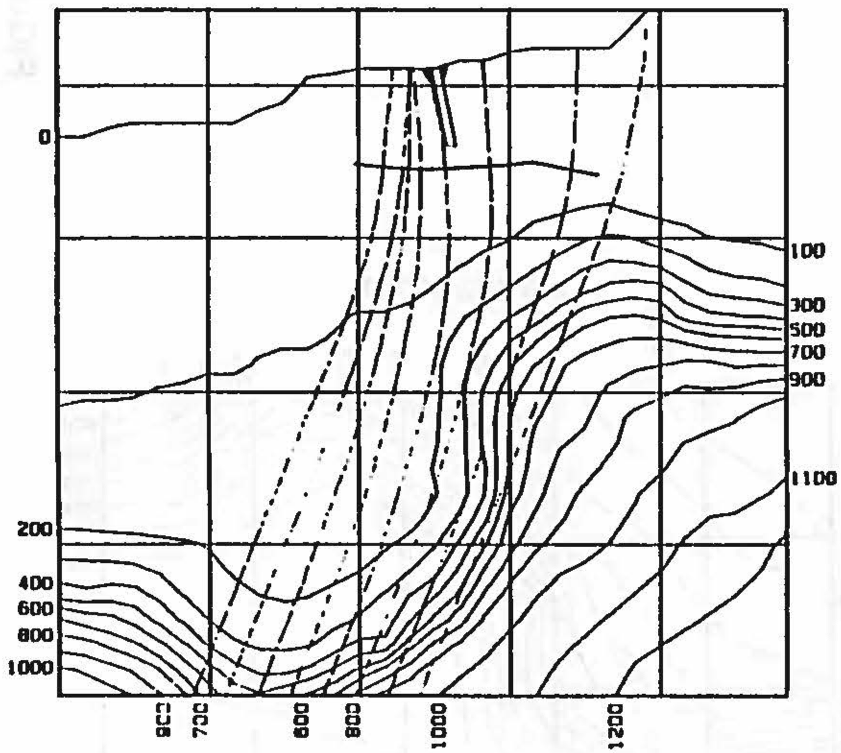
FIGURE 14



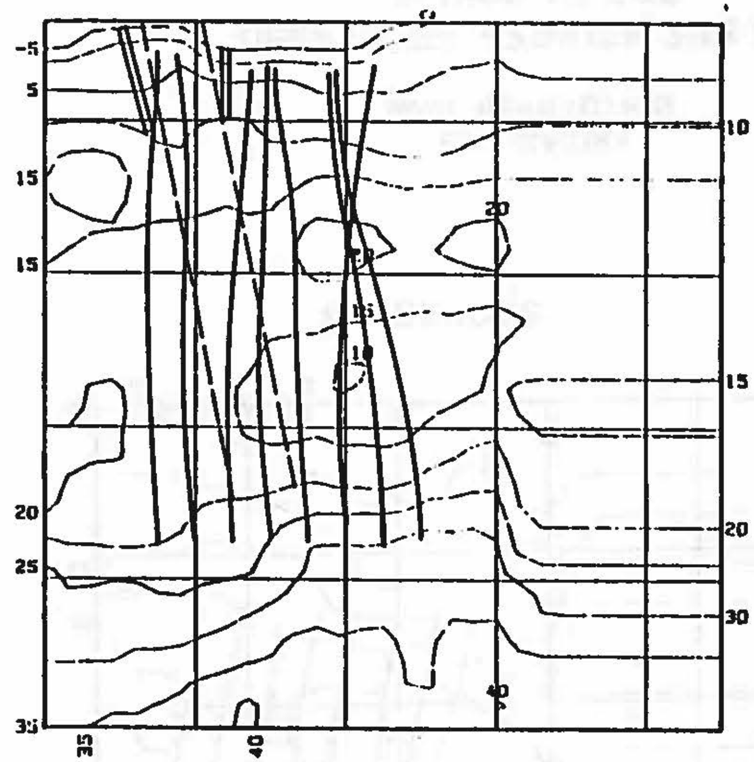
EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 202 DEG.
PERIOD 8 SEC.

FIGURE 15



DEEPWATER

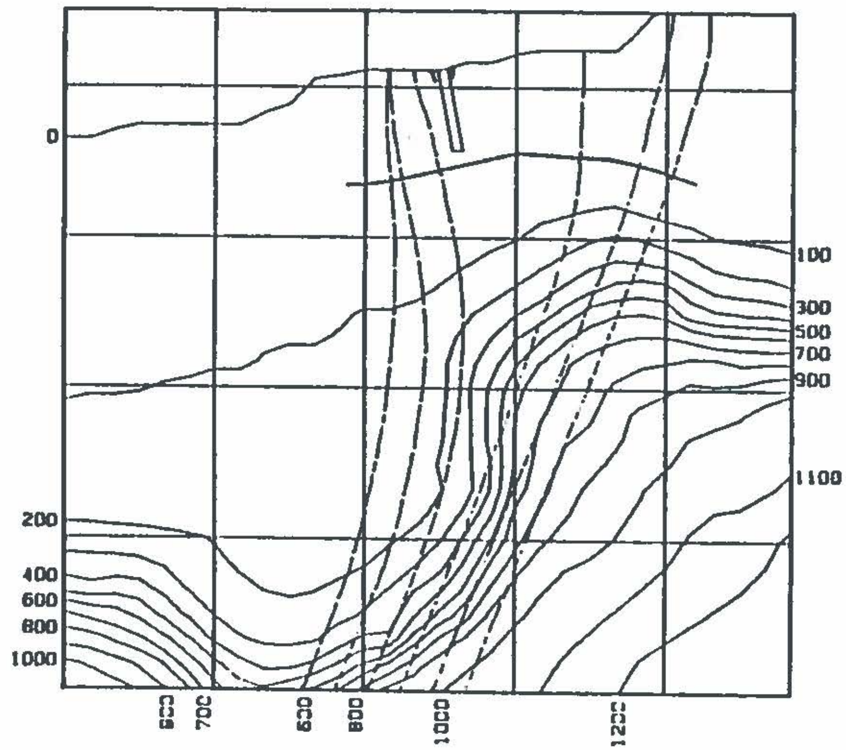


NEARSHORE

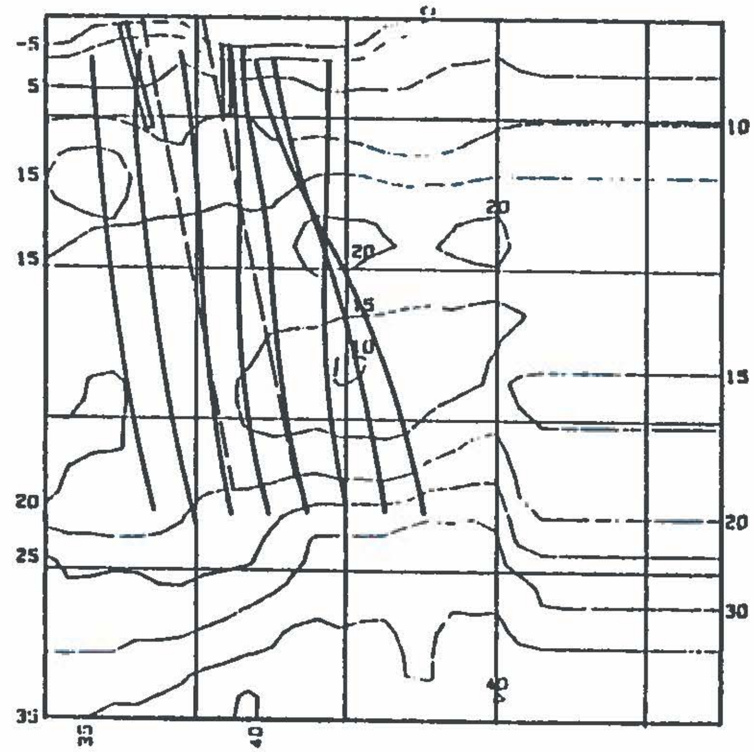
EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 202 DEG.
PERIOD 10 SEC.

FIGURE 16



DEEPWATER

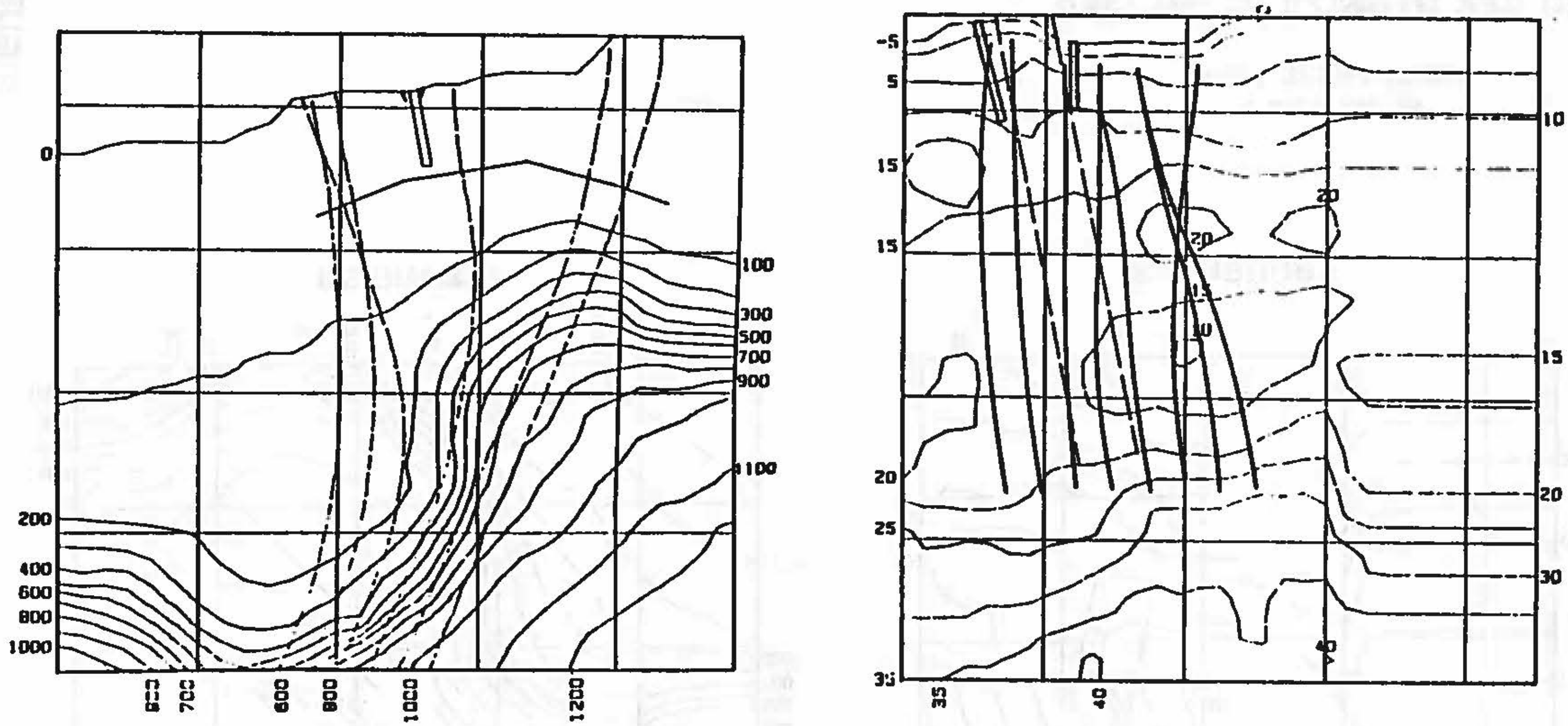


NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 202 DEG.
PERIOD 12 SEC.

FIGURE 17



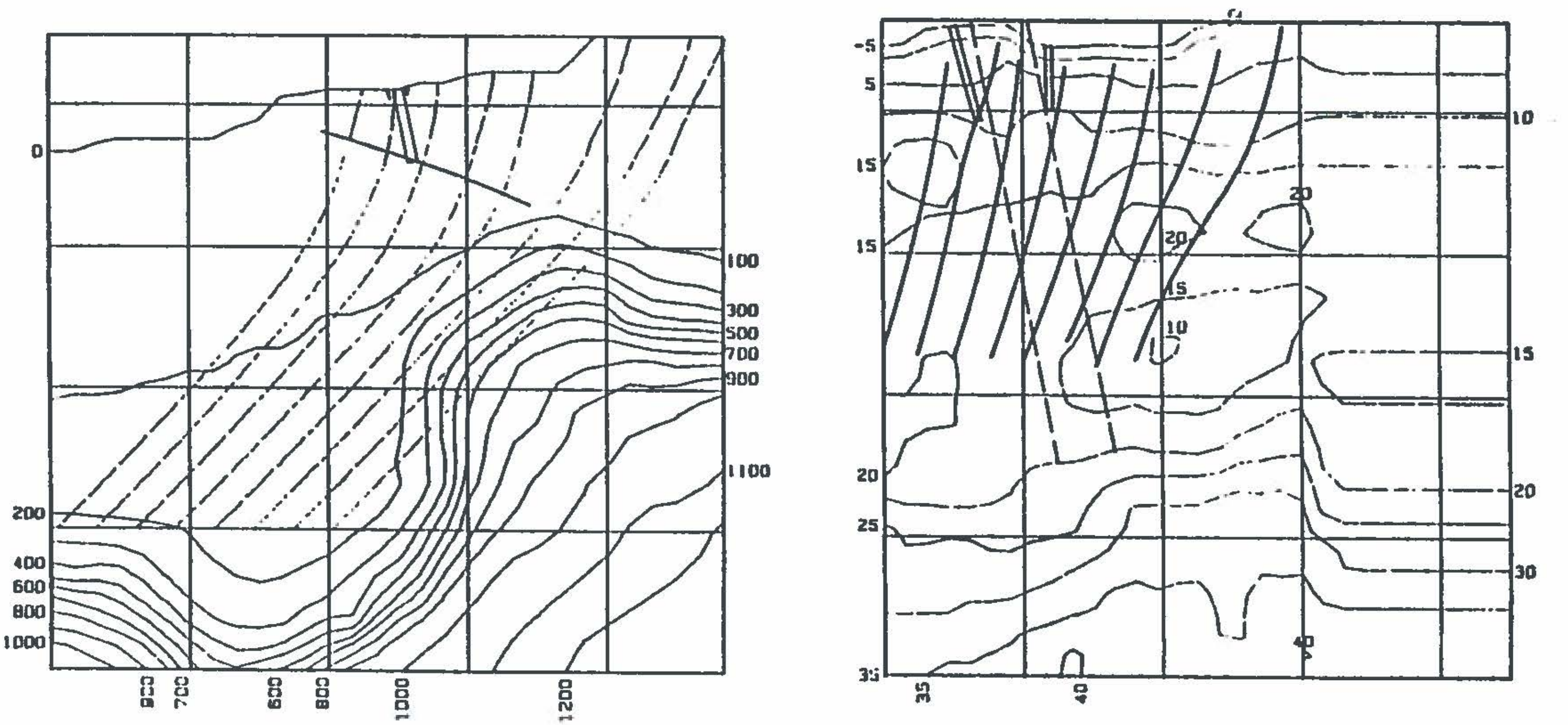
DEEPWATER

NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 202 DEG.
PERIOD 14 SEC.

FIGURE 18



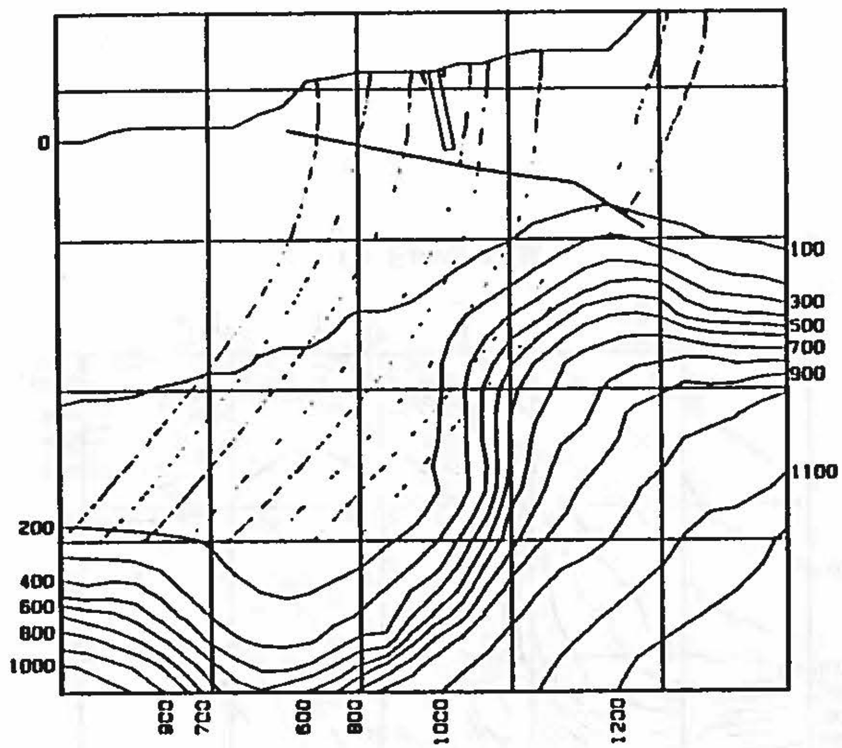
DEEPWATER

NEARSHORE

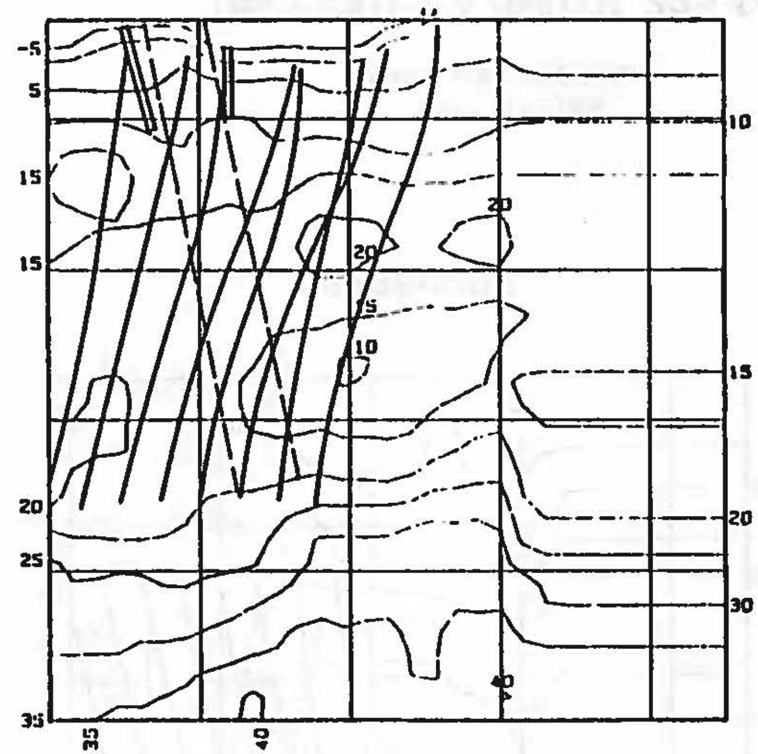
EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 225 DEG.
PERIOD 8 SEC.

FIGURE 19



DEEPWATER

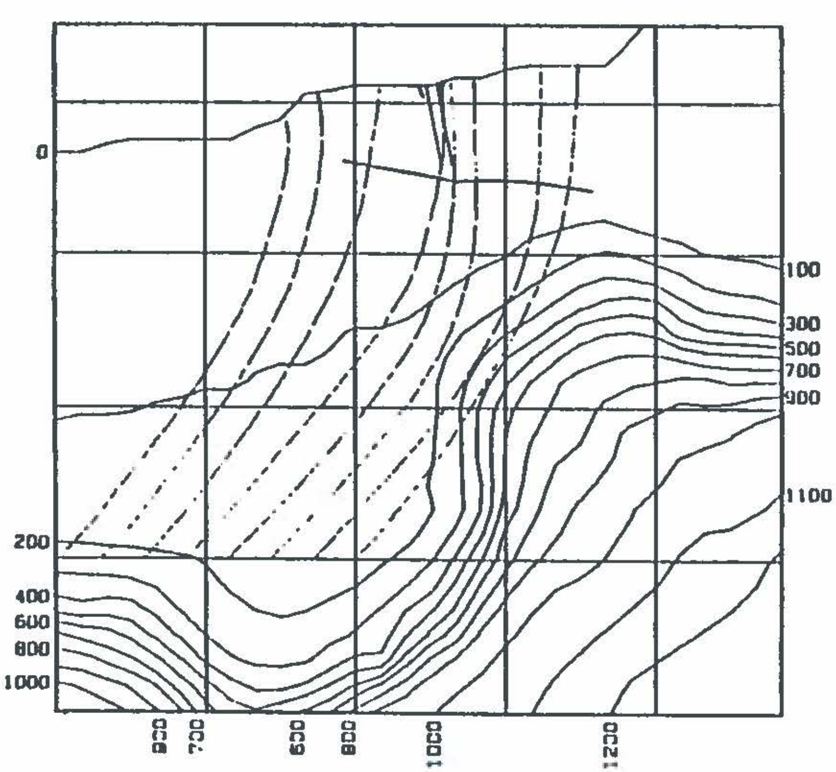


NEARSHORE

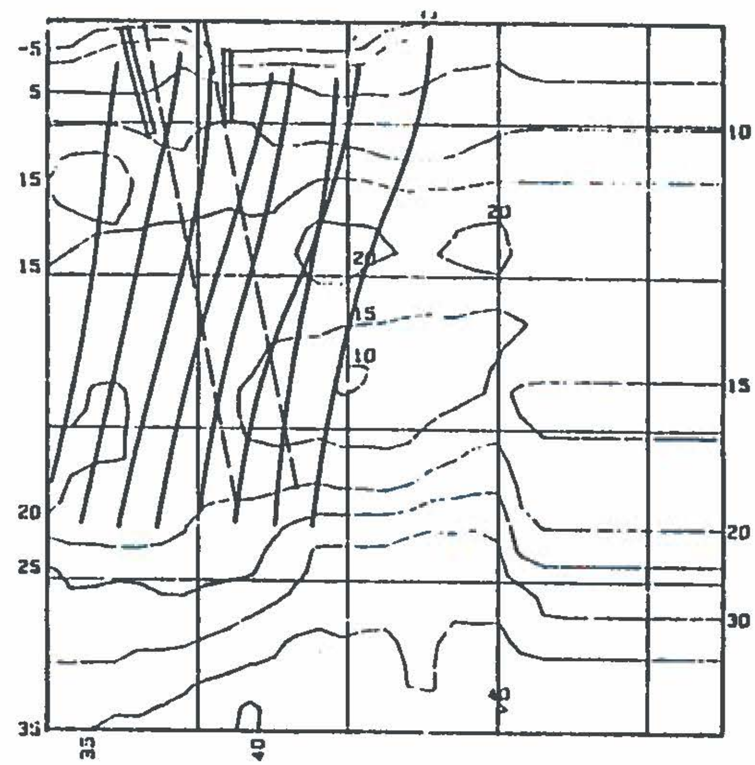
EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 225 DEG.
PERIOD 10 SEC.

FIGURE 20



DEEPWATER

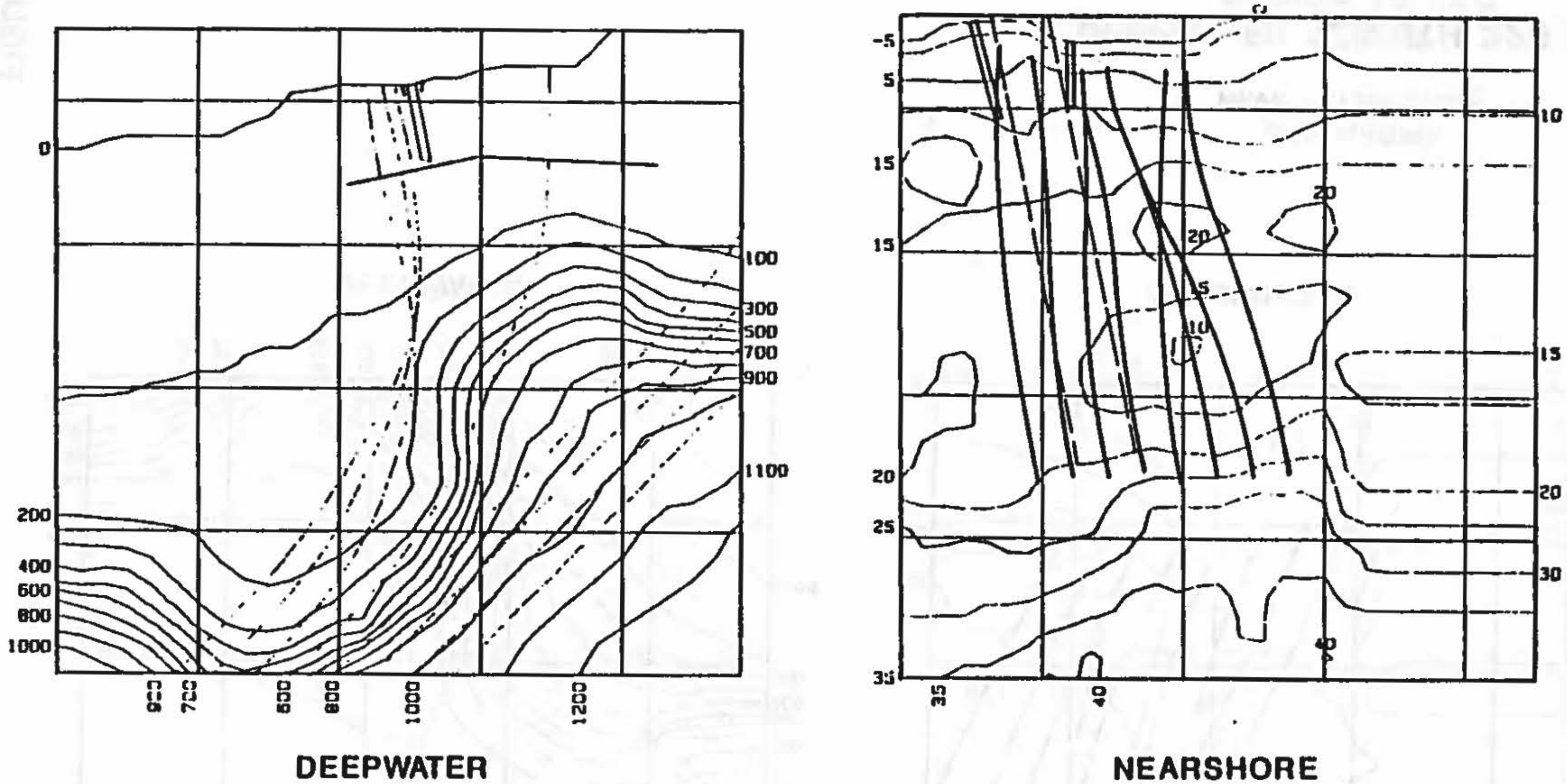


NEARSHORE

EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 225 DEG.
PERIOD 12 SEC.

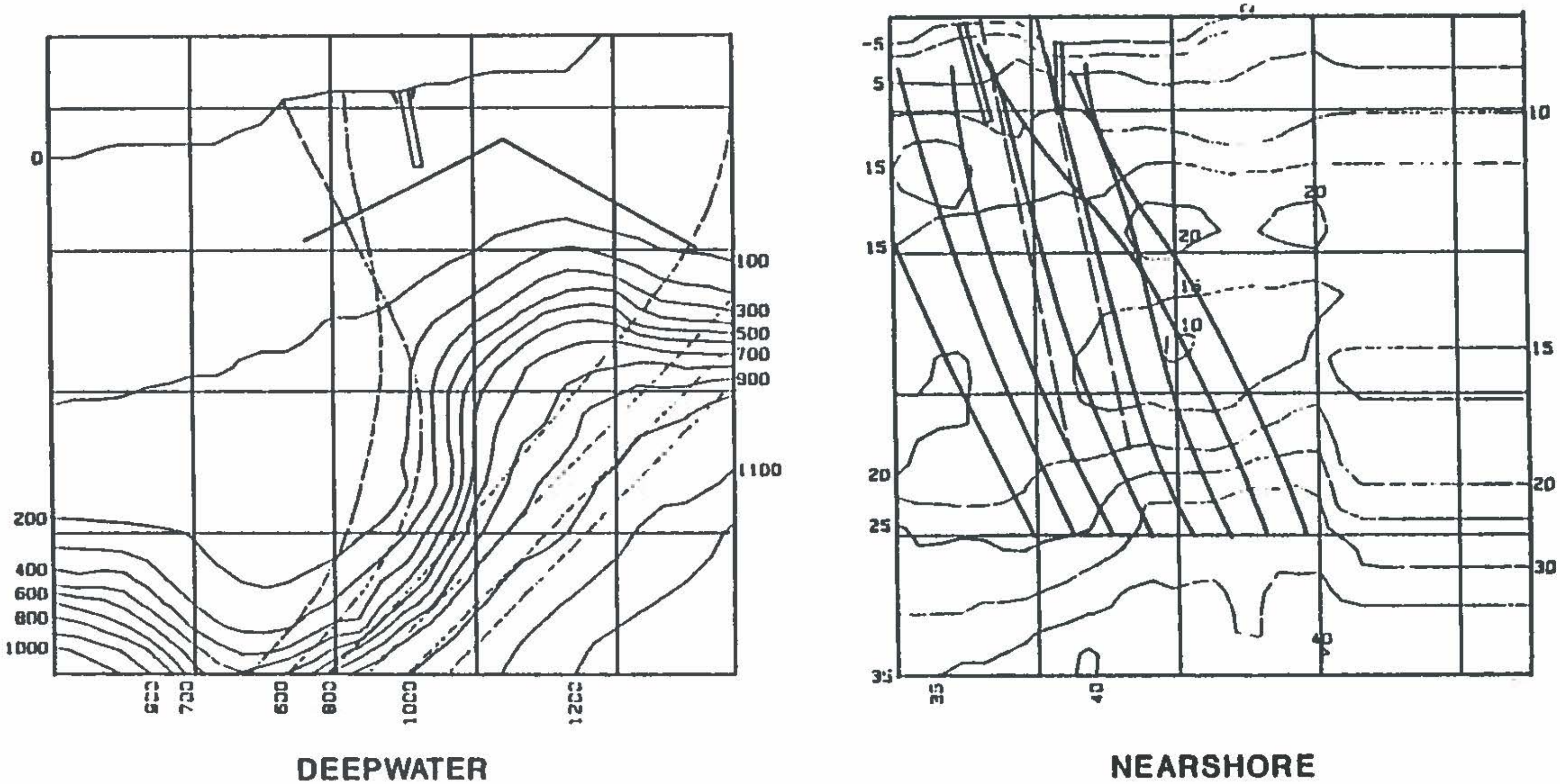
FIGURE 21



EWA MARINA
WAVE REFRACTION

DEEPWATER AZIMUTH 225 DEG.
PERIOD 14 SEC.

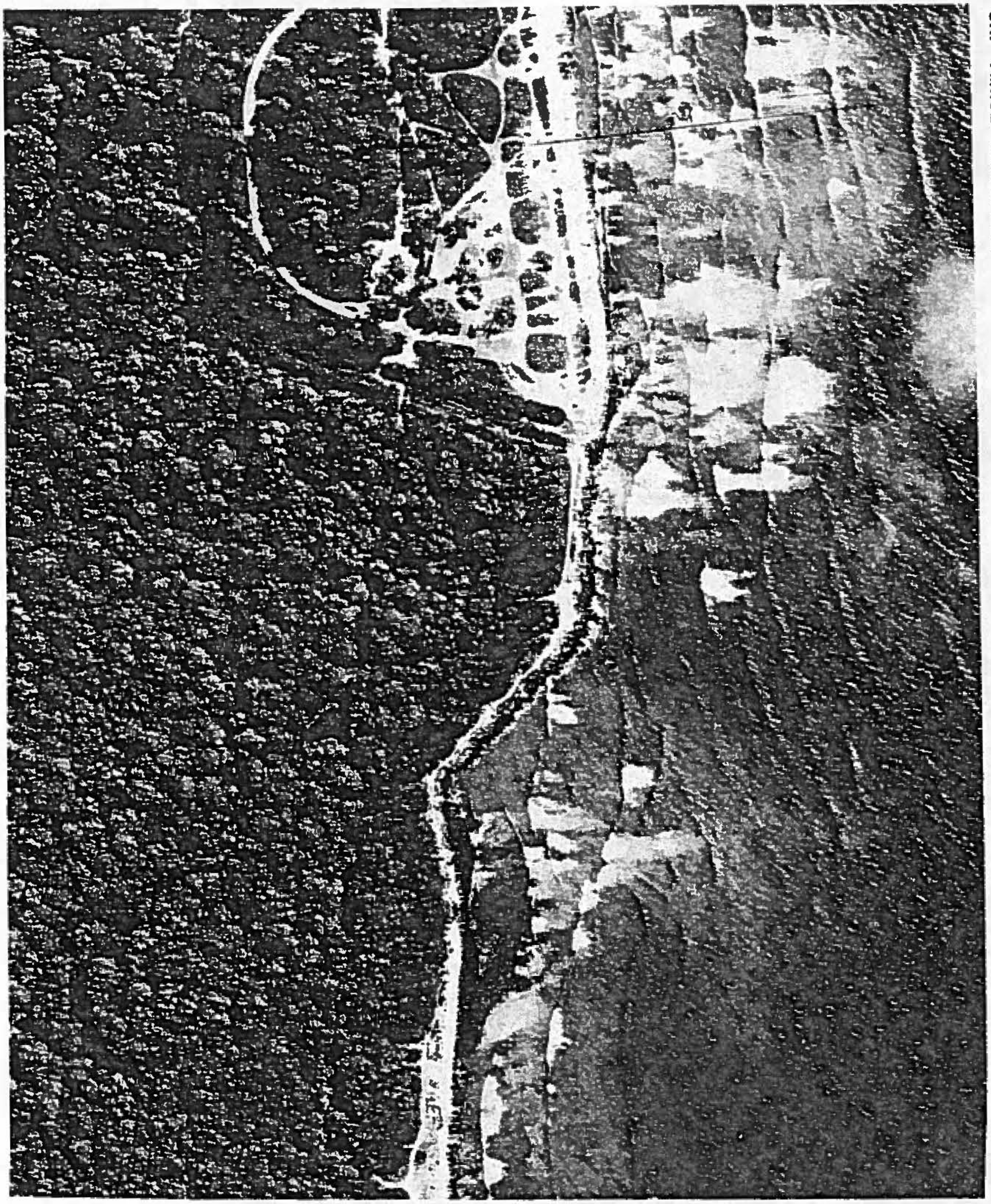
FIGURE 22



EWA MARINA
WAVE REFRACTION

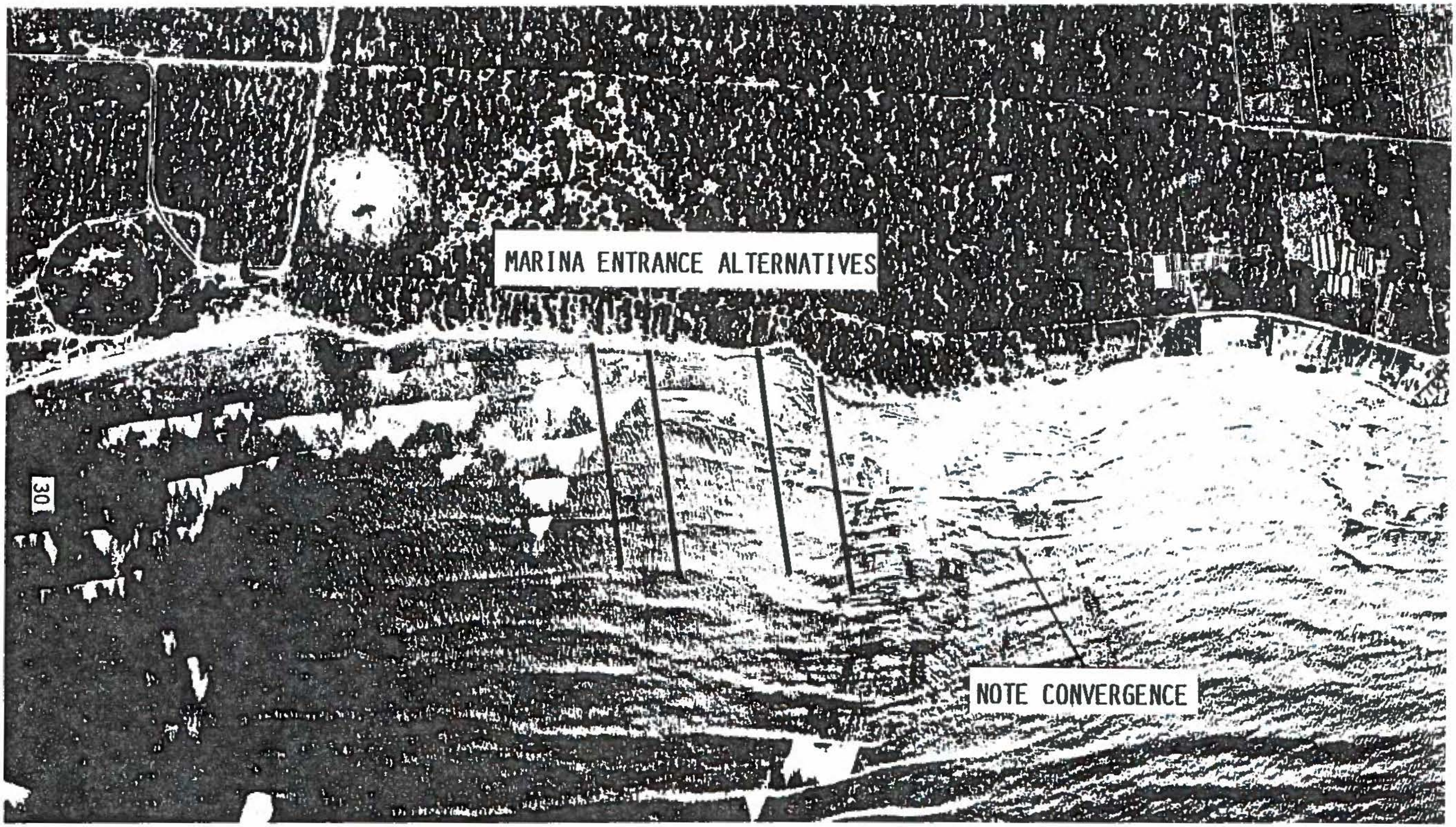
**DEEPWATER AZIMUTH 225 DEG.
PERIOD 16 SEC.**

FIGURE 23



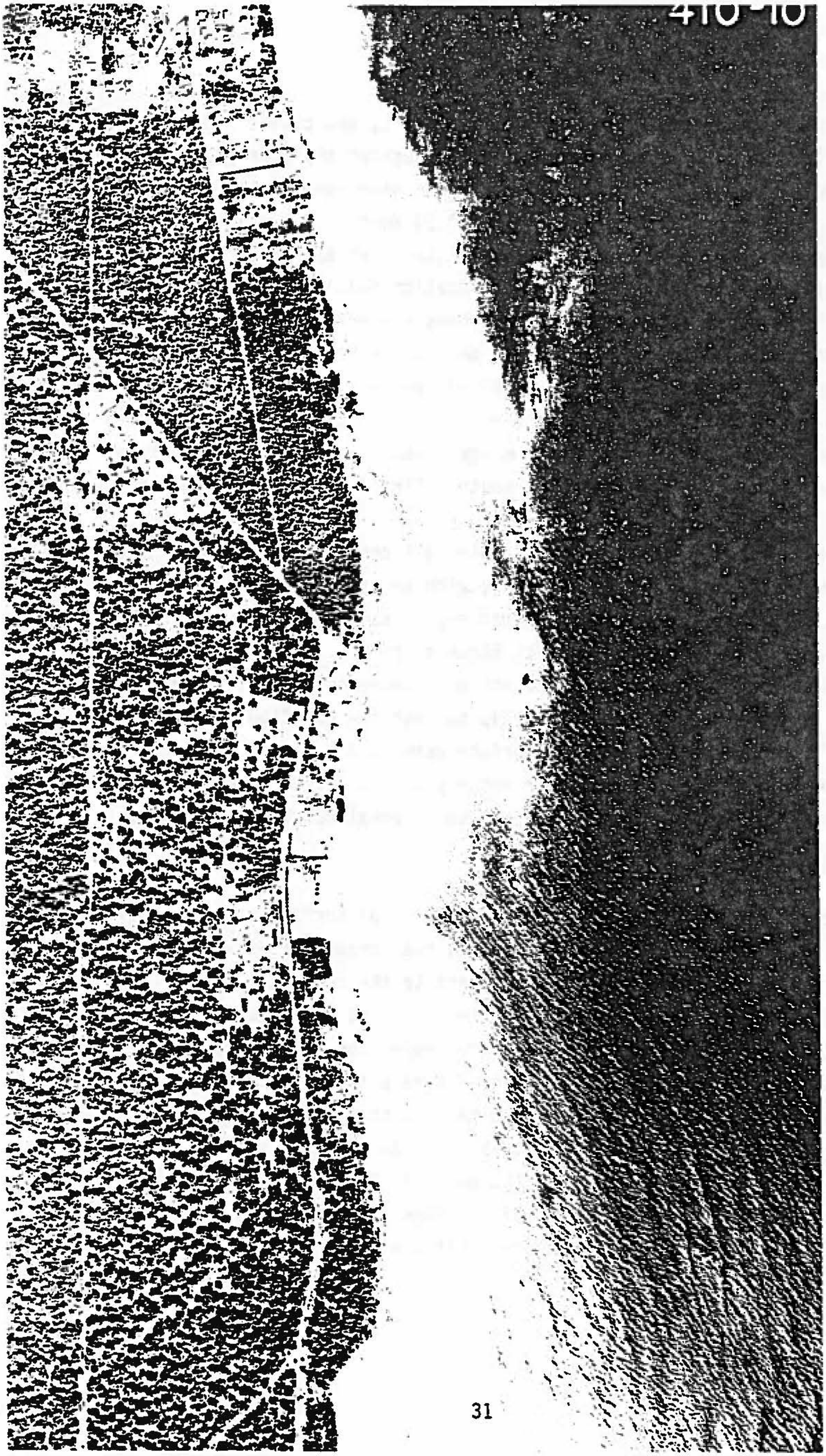
REFERENCE: TOWILL, INC.
(FEBRUARY 1978)

PHOTOGRAPH 2



REFERENCE: TOWILL, INC.
(JUNE 1958)

PHOTOGRAPH 3



REFERENCE: TOWILL, INC. (SEPTEMBER 1950)

PHOTOGRAPH 4

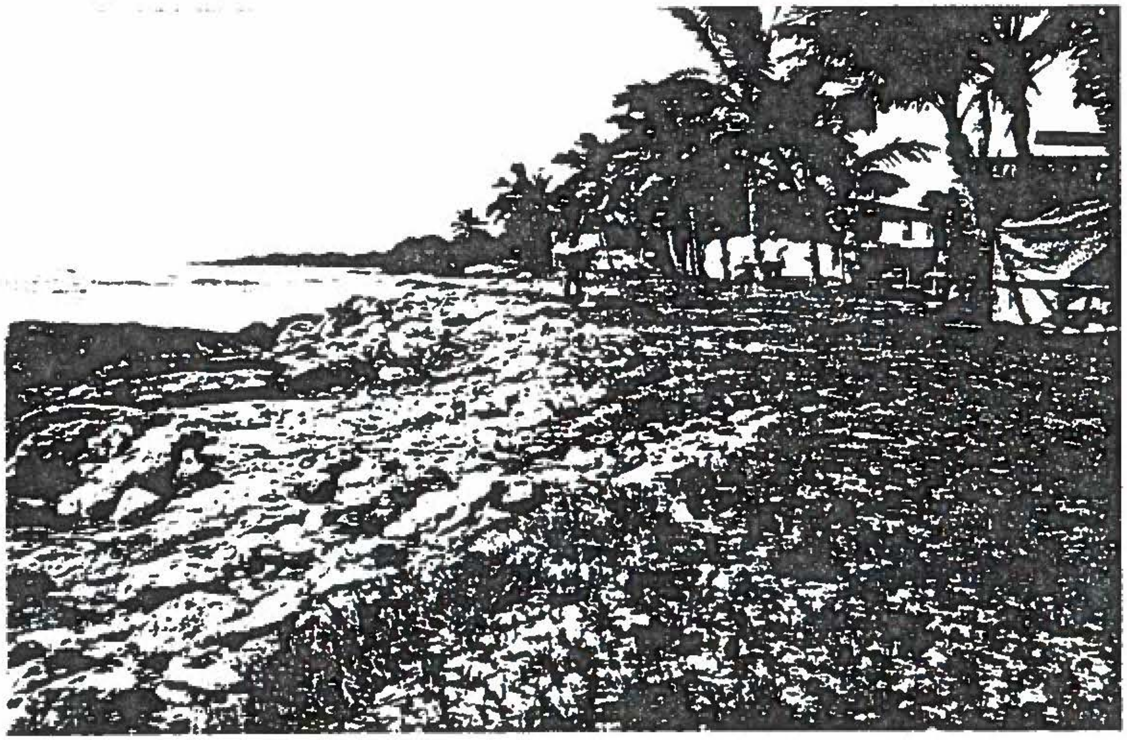
of three components - geostrophic, wind drift, and tidal. Geostrophic flow in Mamala Bay is nearly constant throughout the year and runs westerly at about 0.15 knots. The surface wind current is also to the west during trade wind conditions, at 0.24 knots. It reverses, however, during kona wind conditions and sets easterly at 0.2 knots. Tidal ellipses have been constructed for a station south of Barbers Point. Both the diurnal and semidiurnal ellipses are oriented in a WNW - ESE direction, and both components have maximum velocities of 0.19 knots. Currents are directed easterly on flood, westerly on ebb flows. Oneula Beach is a stagnation point for the semidiurnal current; on flood the eastward flow from Barbers Point meets a westward current from Diamond Head and the combined flow moves south. Directions are reversed on ebb.

The net surface current found by adding all components is always to the west when the trade wind is blowing, with an average speed of around 0.4 knots. Velocities at various depths may be estimated by modifying the wind component in accordance with Ekman's spiral. In deep water off Oneula Beach the subsurface flow has an onshore component. Near the beach an offshore gradient is set up so that the net flow remains parallel to the coast, but the surface water still moves slowly toward the beach while the bottom water returns to sea. Under kona conditions the net flow is toward the east, and semidiurnal reversals can occur with the tides.

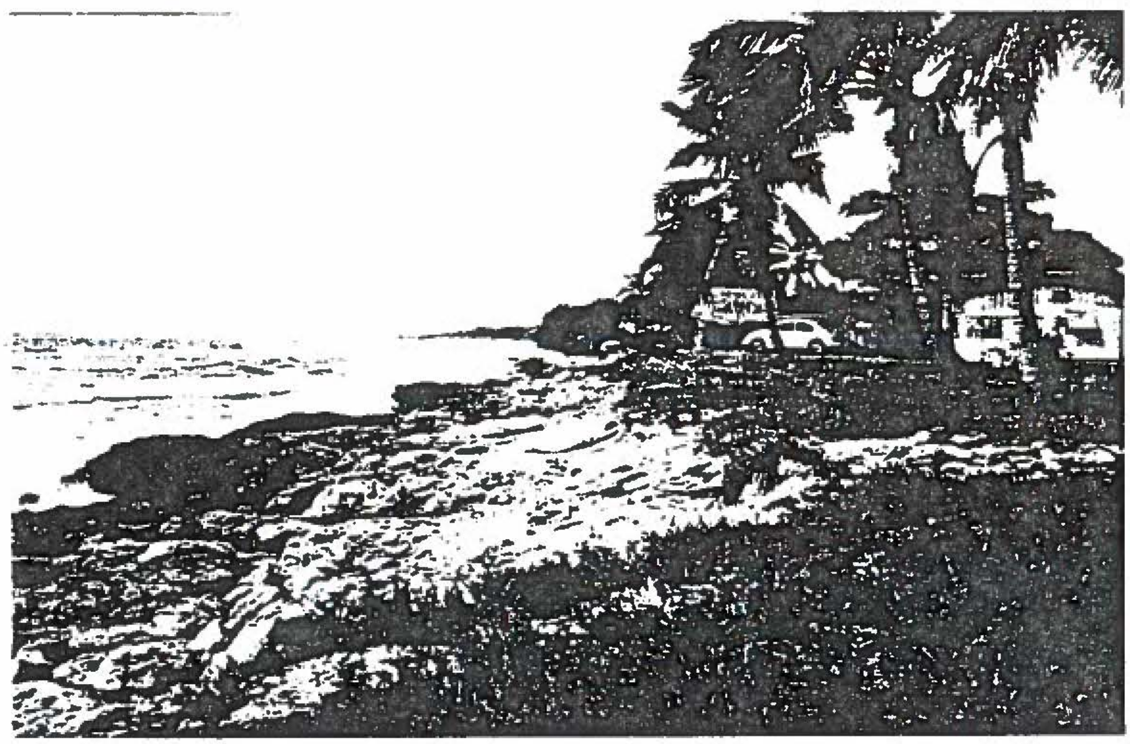
Rip currents are often found near boundaries of surfing sites (Walker, 1978). As waves break over the reef, a mass transport of water is directed toward shore and exits adjacent to the surf zone by rip currents. These rip currents can transport sand into deep water or into sand pockets on the reef for temporary deposition (Moberly and Chamberlain 1964. At some locations, there exist currents that transport material shoreward. Results of a study of Halekulani Channel near Waikiki Beach were discussed by Gerritsen (1972). It was observed that net littoral transport was shoreward in Halekulani Channel. A main rip current was found to exist off the Royal Hawaiian Hotel, carrying large amounts of material offshore. Littoral currents and rip currents contribute to sediment motion and formation of the littoral cell in the area.

The estimated effects of an entrance channel on littoral processes is discussed below. Two alternative entrance locations are presented. An alternative marina entrance is proposed to extend from the rocky point offshore through the reef. The rocky point has been described earlier as the probable end of a littoral cell or partial headland barrier. It is not a large well-defined barrier and probably is not a complete barrier to littoral drift. Dredging a channel through this beach and reef would inevitably trap sand. Littoral transport is primarily onshore and offshore; therefore, the primary adverse affect would be a loss of sand from the Oneula Beach system. Groins or jetties could be constructed to prevent sand from entering the channel from littoral transport during tradewinds and southern hemisphere swell. Shoaling of entrance channels at Ala Wai and Kewalo Basin have been rather insignificant over the years and maintenance dredging has not been required. Honolulu Harbor, which has several streams flowing into it, has had some maintenance dredging. Silt from the streams and clean sand from the reefs have deposited in the channel. Some reef material is expected to fill into the proposed Ewa channel; however, maintenance dredging should be minimal. Clean sand dredged from the channel would be returned to the beach system.

An alternative marina entrance location is approximately 1000 feet west of the beachrock point at the west end of Oneula Beach. The location of the entrance channel would be between two surfing sites identified in an unpublished report by State of Hawaii, Department of Land and Natural Resources titled "The Board Surfing Sites Survey." From ground level photographs (Photographs 5 through 9), the reach of shoreline in the vicinity of the alternative marina entrance is a rocky shoreline with little to no sand. Some littoral material may transverse the rocky shoreline and deposit on Nimitz Beach, however, evidence of appreciable sand along this reach has not been documented nor witnessed. A small sand trap or groin can be located on the east side of the entrance to prevent material that is transported along the shoreline from entering



PHOTOGRAPH 5



PHOTOGRAPH 6

REFERENCE: M & E PACIFIC (1985)

PHOTOGRAPH 7

PHOTOGRAPH 8

REFERENCE: M & E PACIFIC (1985)

the navigation channel. Clean sand should be returned to the beach system.

The west entrance would be located between two surfing sites. As discussed earlier, rip currents are found near the boundaries of surfing sites. From a study of Kewalo Basin by Fallon et al. (1971), a longshore current flowing toward the jetty and crossing the navigation channel was present. It was concluded that the breaking waves from the adjacent surf sites caused a mass transport of water over the reef and the jetty current was considered a rip current.

Consequently, the west channel would be located at the site where rip currents would be expected to occur. The fact that the entrance channel would be between two surf sites indicates a rip current should be located in the site of the proposed channel. The marina channel would therefore not create a rip current. Noda (1985) did not locate a sand pocket in this location. The waves over the reef are the primary forcing function. The channel would refract waves into the surf sites with the probable effect of enhancing wave activity and therefore slightly increasing current velocity. Because this area does not have sand and the effect is local, the impacts on Oneula Beach should be insignificant. Sand is not suspected of leaving Oneula Beach to nourish Nimitz Beach so a channel at this location should have minimal adverse impacts. The sand channel located 1000 feet offshore should have only minor impacts because the existing water depths are 10 feet and greater and the entrance channel would be 20 feet deep.

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APPENDIX 3

WATER QUALITY ANALYSIS

APPENDIX 3

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Water Quality Analysis
For the
Ewa Marina Community Development

Prepared for

M.S.M. & Associates
926 Bethel Street
Honolulu, Hawaii 96813

Prepared by

Moffatt & Nichol, Engineers
250 W. Wardlow Road
Long Beach, CA 90807

April 22, 1986

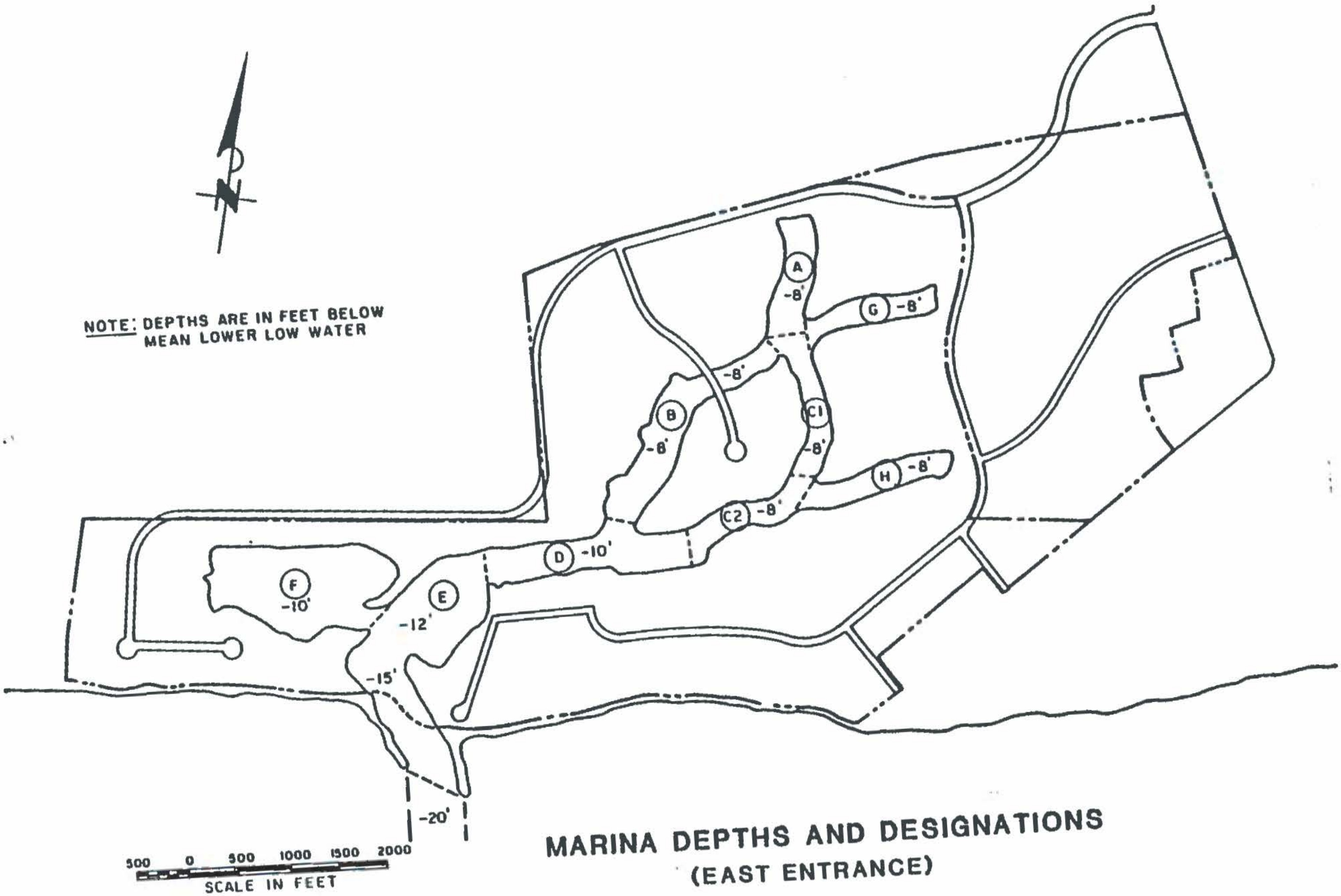
OPERATION IMPACTS

General

The proposed marina will communicate with the ocean only through its 400-foot wide entrance channel, and will receive pollutant inputs of various kinds. The prevailing water quality can be calculated from pollutant inputs together with an evaluation of tidal flushing and other dispersive mechanisms. The first phase of development includes some 89 acres of marina waterways with slips for 1,600 boats. Sources of water pollution originate from the boats, storm runoff, and ground water infiltration. Alternative marina entrances and basin configurations are shown in Figures 1 and 2. Unless otherwise indicated, the water quality analysis results are applicable to both marina systems.

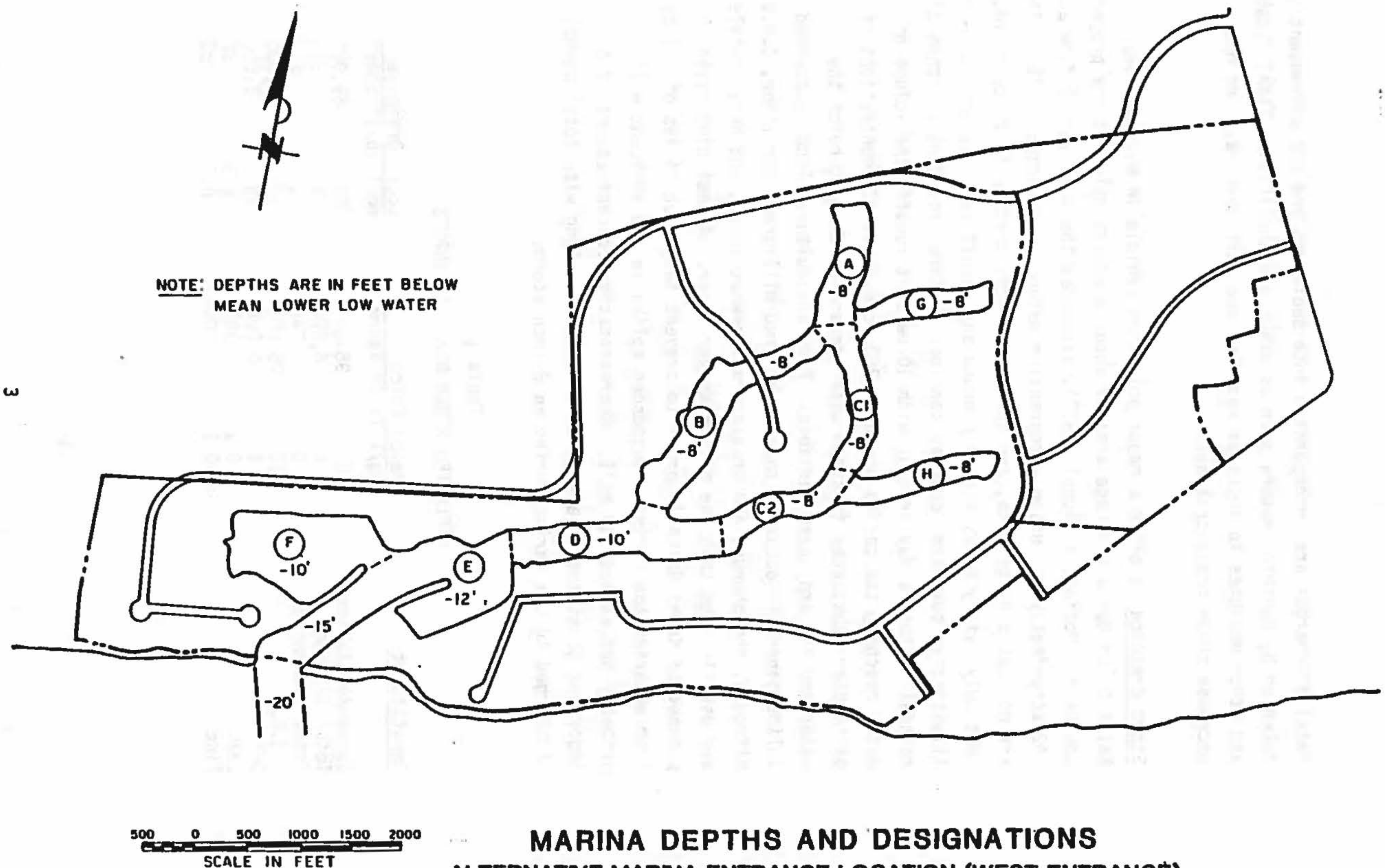
Water Pollutant Sources

Boats release exhaust products from engine operation. Jackivicz and Kuzminski (1973) have reported values of 60 gm C.O.D., 0.05 gm lead, and 10 gm oil produced during the consumption of one liter of gasoline. Gasoline consumption within the marina, estimated on the basis of one trip per boat every two weeks, one mile of marina travel per trip, and 2 gallons of fuel per mile, is about 18 gallons per boat per year. Allowances for C.O.D. and grease inputs under these conditions are 2 lbs. per boat per year and 0.5 lbs. per boat per year, respectively. The antifouling bottom paint used on boats releases copper into the surrounding water. Young et al (1974) have provided a rationale for estimating the input rate; it is based on the frequency of repainting, paint coverage, copper content of paint, and loss between paint jobs, and comes to about 2.5 lb. copper per boat per year. Heads and galleys can contribute organic matter. However, Federal regulations now require marine sanitation devices on all boats equipped with toilets. In most cases, compliance is achieved by means of holding tanks which can be pumped out at a dockside station. Regardless of enforcement, recreational boat operators as a group have always been sympathetic with local non-discharge ordinances and have complied voluntarily.



MARINA DEPTHS AND DESIGNATIONS
(EAST ENTRANCE)

FIGURE 1



MARINA DEPTHS AND DESIGNATIONS
ALTERNATIVE MARINA ENTRANCE LOCATION (WEST ENTRANCE)

FIGURE 2

Metal discharges are incorporated into sediments and are subsequently taken up by benthic feeders such as crabs and shellfish. Tidal flushing and other measures to increase water volume turn-over rates do not decrease these concentrations.

Storm drainage is often a major pollution vehicle in enclosed bays. Kaloi Gulch has a drainage area of about 9 square miles at the project boundary. Moffatt & Nichol (1978), estimated the mean annual flow at 442 acre-feet/year, using a regression method by Yamanaga (1972). There are no usable gauge data, and apparently infiltration is quite rapid, so that only fairly heavy storms produce any runoff into the ocean. For illustrative purposes, one may consider a storm producing 8 inches of rainfall within a day or two; with 10 percent runoff, the volume of water reaching the marina would be 360 acre-feet. Concentrations of particular substances in storm water depend on the nature of the watershed and are quite variable. From agricultural land, suspended solids generally occur at several hundred milligrams per liter, C.O.D., nitrogen, phosphorus, and grease are somewhat lower, and heavy metals are usually less than one milligram per liter. A desilting basin is planned on Kaloi Gulch in order to prevent large quantities of solids from entering the marina. Suspended solids in the effluent will probably not exceed 100 mg/l. Representative concentrations of the important constituents are given in Table 1, along with total quantities discharged to the marina during an 8-inch storm.

Table 1

ESTIMATED STORM DRAINAGE INPUTS

Constituent	Kaloi Gulch		Local Drainage	
	mg/l	lb/8" Storm	mg/l	lb/8" Storm
Suspended Solids	100	98,000	750	69,000
Total Nitrogen	6	6,000	2	500
Total Phosphorus	0.25	240	1	275
C.O.D.	25	25,000	50	14,000
Oil	5	5,000	10	2,800
Lead	0.1	100	0.3	80
Zinc	0.1	100	0.3	80

Storm runoff from the project site itself will be collected in pipe drains, but it is assumed that many of these will flow out into the marina channels. Allowing for as much diversion around the waterways as appears to be possible by gravity, some 400 acres will still be tributary to the marina. Because of the impermeable surface created by development (roofs and pavement), the runoff factor will be greater than for bare land; a coefficient of 40 percent is assumed for an 8-inch storm. The local runoff would then add about 100 acre-feet to the flow from Kaloi Gulch. Concentrations of suspended solids, nitrogen, and phosphorus in Honolulu runoff have been measured by Fujiwara (1973); these data are applicable to the Ewa community. Rounded off values for suspended solids, nitrogen, and phosphorus are the basis for estimated concentrations given in Table 1.

Groundwater Infiltration. Groundwater conditions on the Ewa Plain are described in a report by the U.S. Geological Survey (1973). The upper aquifer is fractured coral limestone. It is overlain by a very shallow soil mantle, apparent in borings made on the project site by Gribaldo and Jones (1973), and is 300 feet deep. Volcanic aquifers lie below the calcareous rock; they contain good quality water and are not hydraulically connected with the upper aquifer. The upper aquifer is highly permeable, and salt water has intruded a considerable distance inland. The water is too brackish for domestic use, but is extensively used for irrigation. The wells and pits from which irrigation water is pumped extend only a few feet below the water table so as to skim off the relatively fresh water floating on the surface. The water is fairly high in nitrate, which originates as fertilizer applied to the cane fields. Table 2 gives partial analyses of ground water samples from wells that draw from the upper aquifer in lands to the north of the proposed community. Nitrate concentrations average about 7 mg/l and are representative of the current load use situation in which nearly all of the Ewa Plain is under sugar cane cultivation.

Table 2
IRRIGATION WELL WATER ANALYSIS

WELL NUMBER	PHOSPHATE PO4 (ppb)	CHLORIDE Cl (ppm)	NITRITE N-NO2 (ppb)	NITRATE N-NO3 (ppm)	NITRATE (as N) (ppm)
1	11	1100	87	41	9.3
2	14	1020	153	34	7.7
3	9	930	87	33	7.5
4	24	830	111	34	7.7
5	23	920	93	27	6.1
6	16	940	105	27	6.1
7	20	870	11	26	5.9
Average	16.71	944.29	92.43	31.71	7.2

*Samples taken January 16, 1986

The water table on the Ewa Plain slopes south from the mountains to the ocean, corresponding to a flow in the same direction. However, near the coast the slope is very flat and the water table elevation is close to mean sea level. Personal communication from Dames & Moore indicate the groundwater flux would be 80 cubic feet/day per foot of aquifer width. Since the east-west extent of the marina system is about 7,000 feet, the daily groundwater influx would be about 6.5 cubic feet/sec (maximum). Nitrogen and phosphorus inputs would be 245 lb/day and 1 lb/day, respectively.

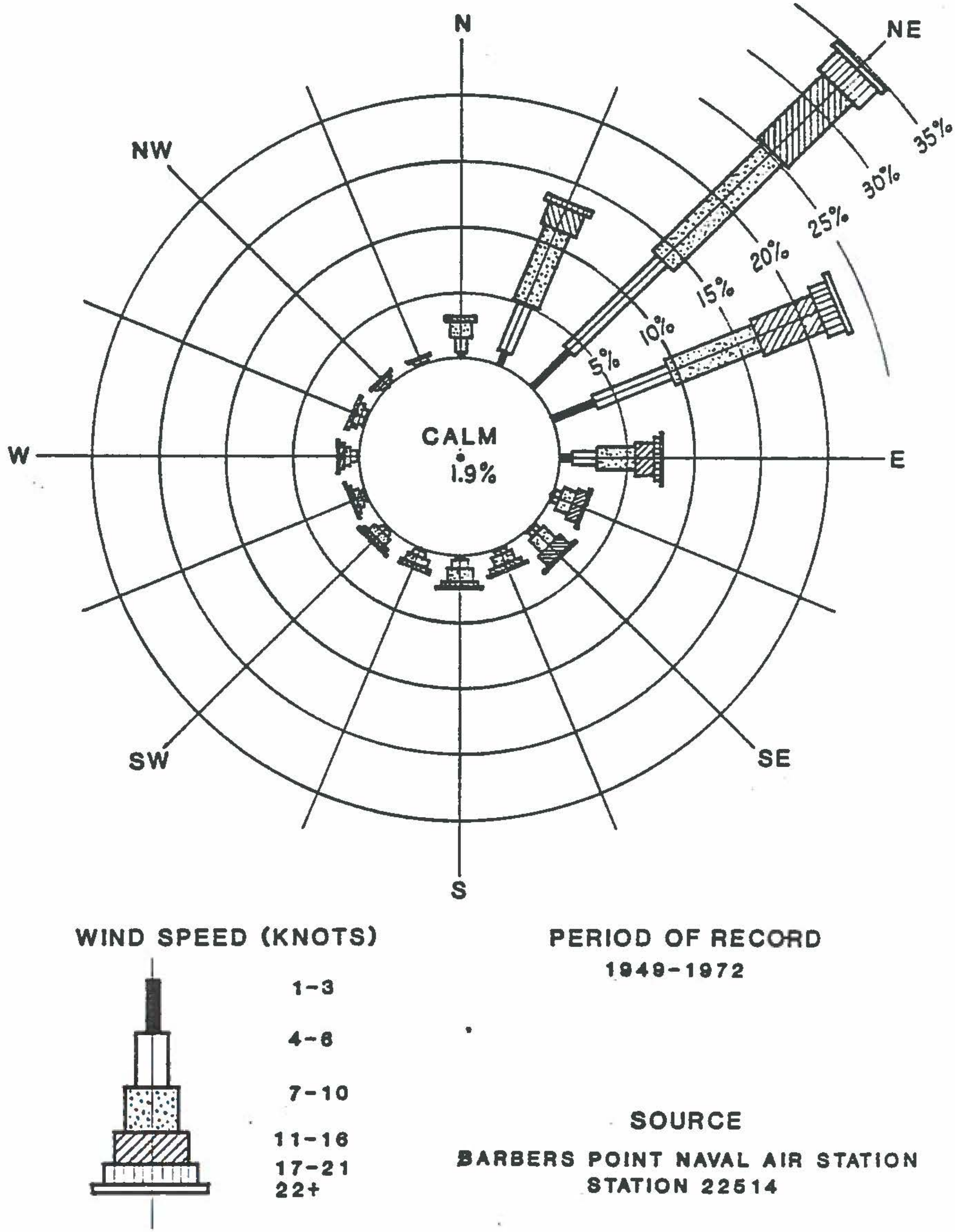
TIDAL FLUSHING

Water quality conditions in the marina channels depend on how fast the various substances present are flushed to sea by tidal and fresh water flows (or removed by some other mechanism). Estimates of turnover rates in the Ewa Marina have been carried out by Moffatt & Nichol (1978) and by Ocean Engineering Consultants (1980). Refinement of the Moffatt & Nichol model has been carried through to provide concentration estimates. Because of the influx of fresh groundwater, it is possible for the marina to become density-stratified. The tendency for stratification has been related to the ratio of the volume of fresh water entering the marina during each tide cycle to the volume of salt water in the flood tide. If this ratio is greater than 0.7, stratification will occur while if the ratio is less than 0.1 then the inlet can be considered to be well mixed (Silvester, 1974). A ratio of 0.056 calculated for the entire marina system with the east entrance location places it in the well-mixed category. Similarily, the ratio for the entire marina system with the west entrance location was 0.054. Table 3 summarizes the calculated ratios for the individual basins and entire marina systems. Basin G is in the partially mixed regime because of its east-west alignment and its relatively small tidal prism. Determination of the degree of mixing does not take into account wind-shear driven currents and inter-mixing of the basins. If conditions in the basin are unacceptable, artificial circulation may be used to improve mixing; discussion is given in the paragraph, "Water Circulation Improvements."

Table 3
DEGREE OF MIXING RATIOS

Basin	East Entrance	West Entrance
A	.073	.073
B	.077	.077
C1	.065	.065
C2	.039	.039
D	.062	.062
E	.056	.051
F	.056	.054
G	.194	.194
H	.058	.058
Entire Marina	.056	.054

Additional energy for mixing is available in the form of wind-generated currents. A wind rose from records compiled at the Barbers Point Naval Air Station is shown in Figure 3. Most of the channel system is aligned more or less parallel to the prevailing trade wind from the northeast. The marina entrance for the alternative entrance location is also aligned parallel to the prevailing winds. Ippen (1966) has provided a criterion for the mixing of estuaries. As applied to the Ewa channels,



PERIOD OF RECORD
1949-1972

SOURCE
BARBERS POINT NAVAL AIR STATION
STATION 22514

WIND ROSE FOR BARBERS POINT NAVAL AIR STATION

FIGURE 3

mixing will occur whenever the fresh water velocity exceeds 0.15 ft/sec. The surface current velocity has been estimated at 2 to 3 percent of the wind velocity (Wu, 1969). Using a conservative value of 2 percent yields a necessary wind speed of 4.4 knots to generate mixing. Due to the alignment of the marina channels with the trade winds, the minimum wind velocity is present approximately 70 percent of the time. Thus, no part of the marina should experience extreme stratification, although the surface water will be somewhat less saline than that at the bottom. The mixing characteristics for the alternative marina entrance is further enhanced due to its parallel alignment to the prevailing trade winds.

Channels B, C, D, and E are aligned in the direction of the prevailing trade wind and will experience a longitudinal circulation current. The strength of the current can be estimated using a formula developed by Banks (1975):

$$q = (4/27) \propto UD$$

where q is the recirculating current per unit width of water surface, U is the wind speed, D is depth, and $\propto$ is a coefficient of proportionality between surface water velocity and wind velocity, generally taken as 0.02. Using an average wind speed of 8 knots from the wind data at Barbers Point, the formula gives wind-induced currents on the order of 100 cubic feet/sec, so that the entire channel section circulates in less than one day. This time period is quite short relative to tidal exchange times throughout the system, and the east-west channel can be considered perfectly mixed. The three north-south channels, A, G, and H, are considered to disperse longitudinally as a diffusion process, using an effective diffusion coefficient of 6 square feet/sec. The remaining channels experience tidal exchange flows equivalent to the prism of a 1-foot twice-daily tide. All channels are also flushed by the distributed fresh groundwater flow totalling 6.5 cubic feet/sec. Quality of the coastal water entering the marina is given in Table 4; they are the averages of forty samples taken over a five-year period by the State Health

Department at Ewa Beach Park. The distribution of flows and inputs is shown schematically in Figure 4. The computed steady state concentrations of the substances of interest are also given.

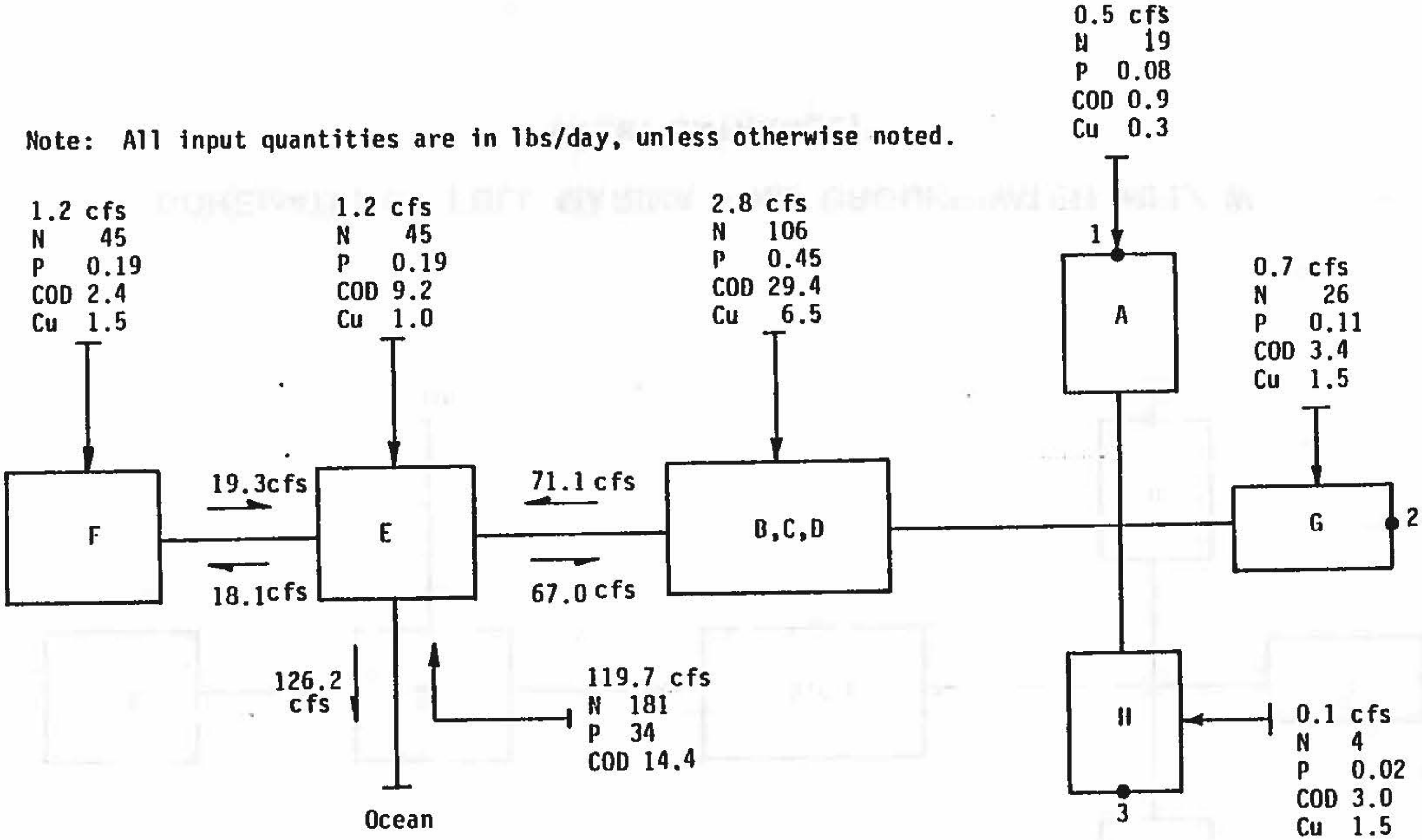
Table 4

COASTAL WATER ANALYSIS ENTERING MARINA

Parameter	Unit	Value
Temperature	°C	25.7
Turbidity	JTU	19.9
Dissolved Oxygen	mg/l	6.70
pH	-	8.11
Salinity	ppth	33.1
Total Nitrogen	mg/l	0.28
Total Phosphorus	mg/l	0.05

Mean residence times fall in the range of 9.0 to 11.2 days except for Channel E, which has a residence time of 5.0 days. Total nitrogen reaches nearly 1.5 mg/l while phosphorus remains the same as the ocean background; organic matter expressed as C.O.D. is negligible everywhere. Copper ranges from 20 to 90 micrograms per liter. These values depend on the assumption that hydraulic flushing is the only removal mechanism, and should therefore be conservative. Salinity in the upper channels is reduced to 90% that of the ocean as a result of the groundwater inflow. Mixing action by wind and current action is likely to be sluggish in the three finger channels (A, G, and H), so that they may become somewhat stratified, with lower salinity near the surface.

Figures 5 through 7 are included for purposes of comparison. The effect of groundwater inflow on residence times in the proposed marina is shown in Figure 5; the additional outflow reduces the flushing time by two days in the inner channels. Figures 6 and 7 show flushing times within the marina as formerly proposed. Its entrance lies easterly of the location now proposed and is aligned perpendicular to the prevailing wind, but otherwise the two layouts are identical. Computed flushing times in the layout with the westerly entrance location are slightly longer. However, keeping the entrance aligned with the wind will tend to increase the exchange flow between the marina and the ocean, since the surface current driven by the trade wind can continue straight out



Resulting Concentrations

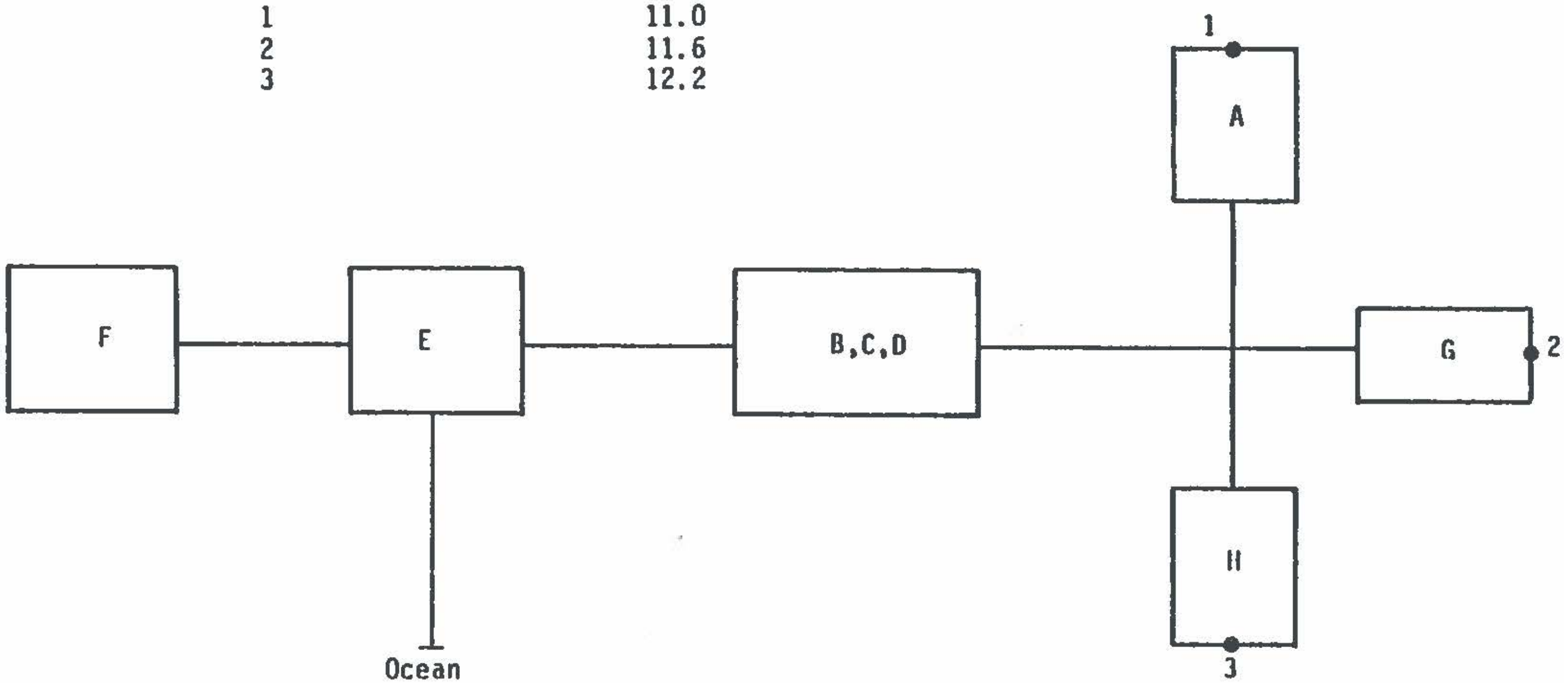
Point	N mg/l	P mg/l	COD mg/l	Cu ug/l	Salt %Sea	Res. Time days
E	0.56	.05	.07	20	95	5.0
F	0.96	.05	.09	30	89	9.8
BCD	0.93	.05	.16	40	89	9.0
1	1.14	.05	.17	40	86	9.9
2	1.45	.05	.23	70	82	9.8
3	1.03	.05	.25	90	88	11.2

SCHEMATIC OF FULL MARINA WITH GROUNDWATER INFLOW

(WEST ENTRANCE)

FIGURE 4

Point	Res. Time days
E	5.2
F	10.7
BCD	9.8
1	11.0
2	11.6
3	12.2

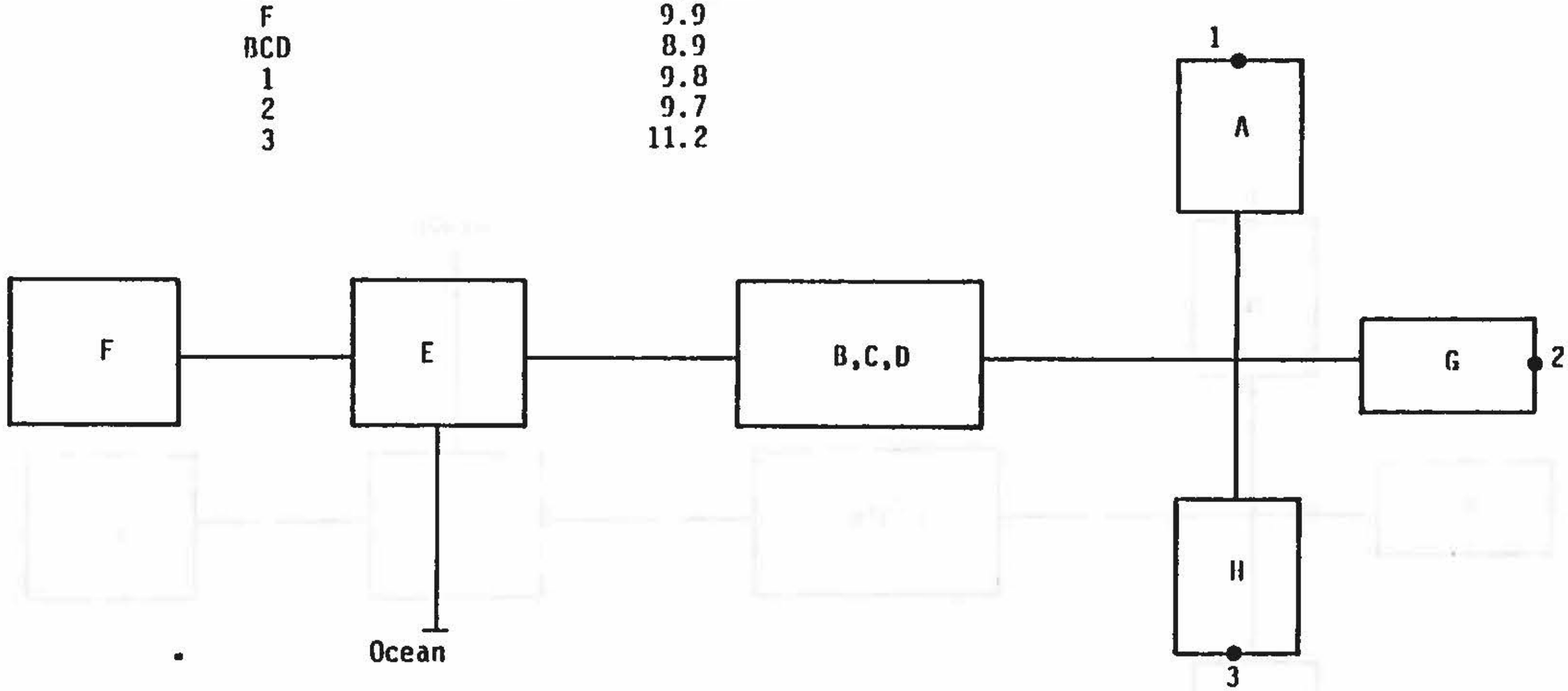


SCHEMATIC OF FULL MARINA – NO GROUNDWATER INFLOW

(WEST ENTRANCE)

FIGURE 5

Point	Res. Time days
E	4.9
F	9.9
BCD	8.9
1	9.8
2	9.7
3	11.2

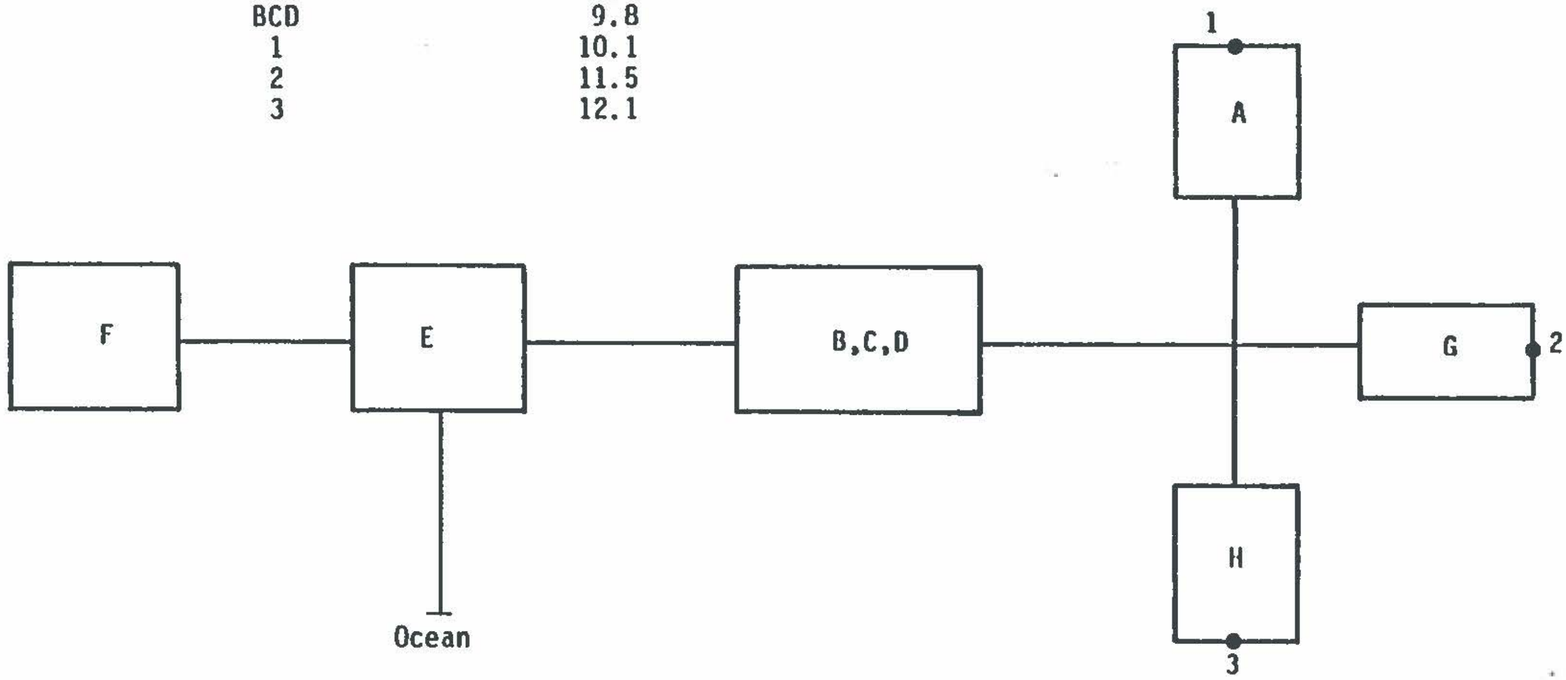


SCHEMATIC OF FULL MARINA WITH GROUNDWATER INFLOW

(EAST ENTRANCE)

FIGURE 6

Point	Res. Time days
E	5.1
F	10.6
BCD	9.8
1	10.1
2	11.5
3	12.1



SCHEMATIC OF FULL MARINA - NO GROUNDWATER INFLOW

(EAST ENTRANCE)

FIGURE 7

to sea. No attempt has been made to quantify this effect in the residence time calculations.

With the passage of severe rainstorms, the large volumes of runoff will completely override normal water quality conditions. Using the example of an 8-inch storm described earlier, the total runoff volume would be about half the total marina volume. Accordingly the series of channels which receive the flow from Kaloi Gulch will become largely displaced by fresh water. In effect, the channel will become the estuary of a river whose velocity may exceed one knot, depending on the storage volume provided in the desilting basin. Concentrations will range from the values given in Table 1 down to a small fraction of these values near the entrance. Runoff will cease soon after it stops raining, and the water will gradually revert to normal; the time required will be on the order of the mean residence times given in Figure 4. Several marinas in southern California receive significant storm discharges, and two of them -- Newport Harbor and Sunset Bay -- are strongly affected because of relatively large tributary watersheds. During high runoff all of the water area become beige colored by the suspended silt, and the concentrations of other parameters are elevated. The water clears in about one week after the rain stops. The phenomenon has little adverse effect on boating, and both of the harbors mentioned support abundant fish populations.

Effects of the marina development on ocean water quality will be small, and in some respects, beneficial. All of the nitrogen carried into the marina with the groundwater flow is reaching the ocean directly at the present time. Storm runoff to the ocean will increase somewhat because of the development's impervious surfaces, but the amount of silt and nutrients will be reduced by sedimentation in the Kaloi Gulch debris basin and in the marina itself. The concentrations occurring in the marina entrance channel will dilute slowly as the plume is drawn out by the littoral current.

State water quality standards are given in Chapter 37-A of the Public Health Regulations (April 1984). They include basic criteria applicable to all waters, and also more specific criteria for several types of marine and inland water bodies. The basic section provides that all waters shall be free of the following substances attributable to controllable pollution sources:

(A) Materials forming objectionable bottom deposits.
(B) Floating material such as debris, oil, and scum.
(C) Substances producing objectionable color or turbidity in the receiving water or tastes in the flesh of fish.
(D) High temperature, pathogenic organisms, and materials in quantities harmful to human, animal, plant or aquatic life.
(E) Substances producing undesirable aquatic life.
(F) Soil particles eroded from disturbed land areas.

While these regulations are somewhat subject to interpretation, it appears that the only one which may require mitigation measures is (E), discharge of substances producing undesirable aquatic life. Groundwater seepage into the marina is fairly high in nitrate, which may stimulate the growth of planktonic algae enough to impair water clarity and possibly even to suppress dissolved oxygen.

One of the types of marine waters for which specific criteria have been set up are embayments. On Oahu the specific rules are applicable to the Ala Wai Boat Harbor, Kewalo Basin, Keehi Lagoon, Barbers Point Harbor, and several others. Embayments are designated as "wet" if the average daily fresh water inflow equals or exceeds one percent of the bay volume per day. Different numerical limits are provided for wet and dry embayments. Table 5 lists the regulated parameters and their limits. As a public water body, all or part of the Ewa Marina might be placed in the group of harbors subject to the limits of Table 5. The "wet" criteria will apply since the daily groundwater inflow will be greater than 1 percent of the marina volume. It should be noted that the coastal water along most of Oahu's south shore already exceeds several

TABLE 5

WATER QUALITY LIMITS FOR MARINE EMBAYMENTS

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value
Total Kjeldahl Nitrogen (ug N/1)	200.00* 150.00**	350.00* 250.00**	500.00* 350.00**
Ammonia Nitrogen (ug NH_4-N/1)	6.00* 3.50**	13.00* 8.50**	20.00* 15.00**
Nitrate & Nitrite Nitrogen (ug[NO_3+NO_2]-N/1)	8.00* 5.00**	20.00* 14.00**	35.00* 25.00**
Orthophosphate Phosphorus (ug PO_4-P/1)	10.00* 7.00**	25.00* 12.00**	40.00* 17.00**
Total Phosphorus (ug P/1)	25.00* 20.00**	50.00* 40.00**	75.00* 60.00**
Light Extinction Coefficient (k units)	0.40* 0.15**	0.80* 0.35**	1.20* 0.60**
Chlorophyll a (ug/1)	1.50* 0.50**	4.50* 1.50**	8.50* 3.00**
Turbidity (Nephelometric Turbidity Units	1.50* 0.40**	3.00* 1.00**	5.00* 1.50**
Nonfilterable Residue (mg/1)	25.0* 15.0**	40.0* 25.0**	50.0* 35.0**

*"Wet" criteria apply when the average fresh water inflow from the land equals or exceeds 1% of the embayment volume per day.

**"Dry" criteria apply when the average fresh water inflow from the land is less than 1% of the embayment volume per day.

Applicable to both "wet" and "dry" conditions:

pH Units shall not deviate more than 0.5 units from a value of 8.1.

Dissolved Oxygen - Not less than 75% saturation.

Temperature - Shall not vary more than 1°C from ambient conditions.

Salinity - Shall not vary more than 10% from natural or seasonal changes considering hydrologic input and oceanographic factors.

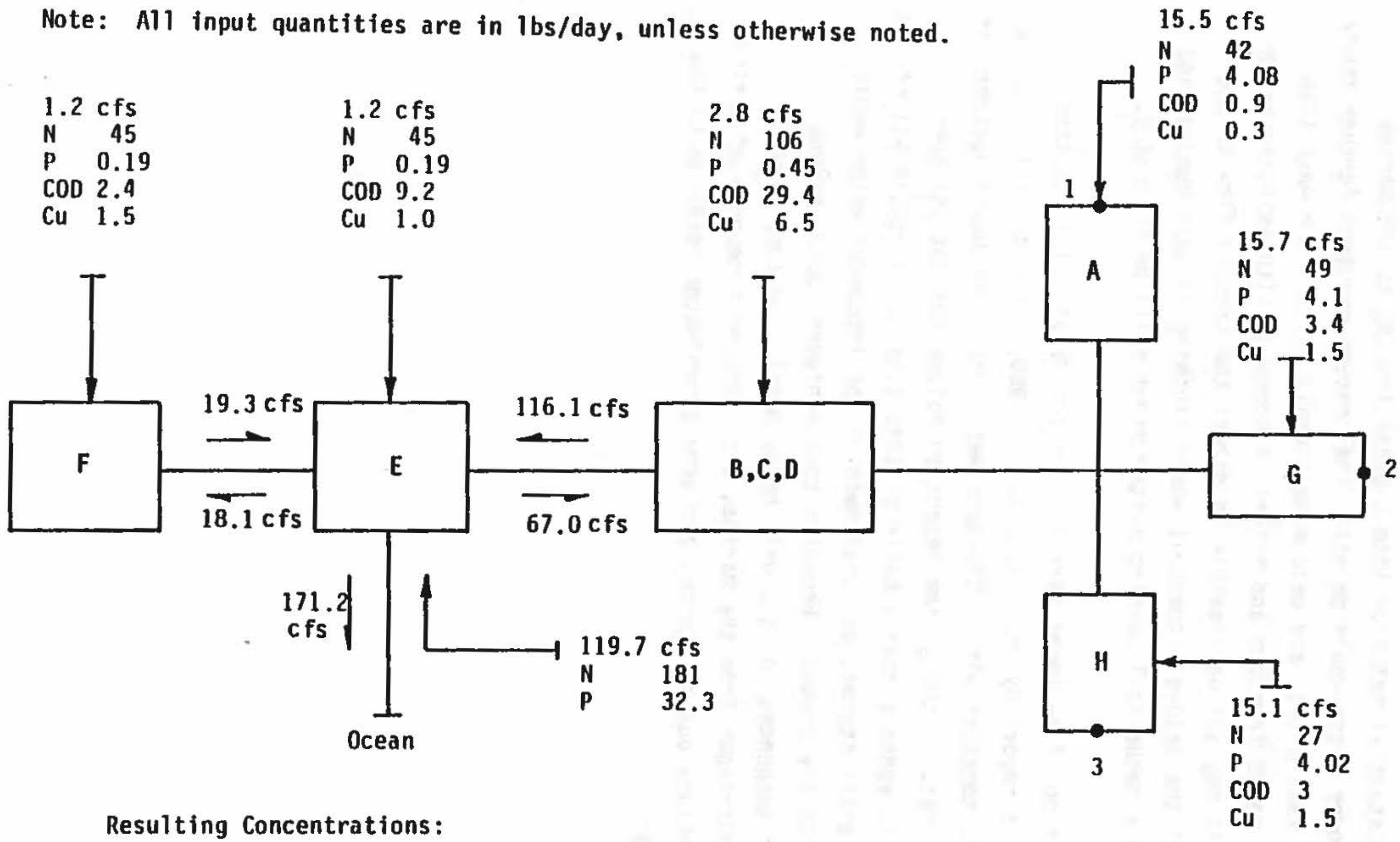
of the limits, including those for Kjeldahl nitrogen, total phosphorus, and turbidity.

Water Circulation Improvements

The calculated concentrations of nutrients and copper in the marina are similar to levels observed in southern California harbors used extensively for swimming and fishing, as well as boating. The Oahu climate is different, however, and in particular the water temperature is higher and more nearly constant. Phytoplankton growth stimulated by relatively high nutrient concentrations could leave the water with more turbidity than some marina users might prefer. The net growth rate of phytoplankton has been measured at other Oahu locations (Hawaii Kai and Kaneohe Bay) with values between 10 percent and 25 percent per day. At the higher end of this range, blooms could be generated in portions of the marina where the residence times are longer than 4 days. The intensity and frequency of algae blooms cannot be readily predicted; they may even be forestalled completely by predation or by the removal of soluble nitrogen through other natural processes. If control of algae growth should prove necessary, the residence times throughout the marina can be greatly reduced by introducing flushing flows of sea water at the upstream ends of the marina fingers. An example of this principle for 15 cubic feet/sec of sea water being delivered to the north ends of Channels A, G and H is worked out in Figure 8. The improvement in flushing rate is considerable, and the salinity is raised and made relatively uniform within the marina. Nitrogen and phosphorus concentrations are approximately 50 percent less than for the same initial conditions under natural circulation. A pumping system which obtained sea water from the ocean could be operated only when water quality conditions warranted, and left idle the rest of the time.

Another possible means of improving interior water circulation is to force ocean water through the marina by means of a wave trap as described by Gerritsen (1980). This device would consist of a 200-foot wide artificial inlet between two jetties. Located at the east edge of the project area on Oneula Beach, waves breaking in the inlet would

Note: All input quantities are in lbs/day, unless otherwise noted.



Resulting Concentrations:

Point	N mg/l	P mg/l	COD mg/l	Cu ug/l	Salt %Sea	Res. Time days
E	.54	.05	.05	10	96	3.7
F	.93	.05	.07	30	90	8.6
BCD	.67	.05	.09	20	94	4.8
1	.56	.05	.04	10	96	2.3
2	.59	.05	.05	20	95	1.1
3	.36	.05	.04	20	99	1.0

SCHEMATIC OF FULL MARINA WITH ARTIFICIAL CIRCULATION

(APPLICABLE TO BOTH MARINA SYSTEMS)

FIGURE 8

produce a substantial net flow into a canal leading to the marina interior. Power costs would be nil. The concept requires further study to establish feasibility and determine overall costs. The wave trap would occupy beach frontage and interfere somewhat with existing beach uses. Also it may not be feasible to direct the trapped flow to the north ends of the dead-end channels where flushing is most needed, and in that case a mechanical pumping system might still be necessary.

The interception of sediment carried down the Kaloi Gulch has been discussed in a report by Hee & Associates (1980). Two desilting basins are proposed, together with a 150-acre water retention basin upstream of the project area. Although the retention volume has not yet been determined, it appears that a basin of this size could retain all of the runoff from small storms, and that much of the impounded water would percolate into the ground. Benefits thus achieved would include diversion of suspended solids, oil, heavy metals and considerable amounts of nutrients from the marina, also reduced frequency of marina water disturbance due to storms, and some groundwater recharge to the upper aquifer.

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Response to Concerns Regarding
Water Quality

Prepared by

Dr. Jed Hirota
Associate Professor
Marine Biology and Oceanography
University of Hawaii

Prepared for

Dames and Moore
1144 10th Avenue
Honolulu, Hawaii 96816

April 30, 1986

Wednesday, 30 April 1986

Attn: Ms. Jennifer Kleveno
Dames & Moore
1144 10th Ave., Ste 200
Honolulu, HI 96816

Dear Ms. Kleveno:

The following letter is in response to concerns regarding effects of groundwater on the water quality of the proposed Ewa Marina project your firm is working on.

Regardless of the particular configuration selected for the Ewa Marina project (East vs. West entrance), it will be highly unlikely that State Water Quality Standards for Marine Embayments (see Table 5) can be met for all criteria because of two major factors:

1. Marine, coastal water quality values monitored by the State Department of Health over a five year period show (Table 4) already elevated levels of total nitrogen (TN) and total phosphorus (TP) at Ewa Beach Park; these data suggest but do not prove that the Ewa Plain groundwater already has an effect of enrichment on the coastal zone through diffuse inputs. These coastal waters are the "source" waters for the Ewa Marina and now contain various nutrient and particulate levels which shall characterize waters for the new marina. Since these waters are already at or in excess of some water quality limits, it would seem unreasonable to expect that the marina waters would be significantly better (e.g., compare TN and TP values for Tables 4 vs. 5).

2. Groundwater influx to the dredged marina amounts to some 561,600 ft^3/day (ca. 16,000 m^3/day), or about 1.15% of its estimated volume of 48,787,200 ft^3. This groundwater has very high levels of nitrate (ca. 7.2 mg N/liter) and total nitrogen (ca. 14 -20 mg N/liter, assuming that the dissolved organic nitrogen equals the particulate organic nitrogen), which when added to the relatively rich coastal water, would exceed the limits for TN and probably for TP as well, although to a much lesser extent. It should also be noted here that because diffuse-source groundwater inputs to the coastal waters are presumably already occurring, construction of the Ewa Marina could simply modify locations of the input source rather than cause major changes in water quality per se.

Fortunately, the phosphorus content (as phosphate) of the groundwater and the marine coastal waters at Ewa Beach is much less than nitrate and total nitrogen, in both absolute amounts and by nominal atomic ratio of 16:1 (N:P) assimilated on average by the marine plants for their nutrition. Thus, whereas dissolved nitrogen as nitrate and dissolved organic nitrogen (DON) may exceed the State Water Quality Limits, it appears that phosphorus will be much lower, closer to compliance, and will be the limiting micro-nutrient for plant cell growth, considering the input ratios for irrigation well water data (Table 4). Conservative calculations from groundwater phosphate levels suggest an expected particulate loading of 40 to 120 μg N/liter, or 27 to 80% of the geometric mean limit of 150 μg N/liter (Table 5). Once the marina is operational, the mixing from the winds and the tidal exchange between the marina and the coastal waters should flush out about 9 to 20% of the marina on a daily basis, depending on location within the marina (see Figure 4). Additionally, elevated particulate organic nitrogen (PON) levels from the uptake of groundwater nutrients and algal growth will be suppressed to an extent by natural populations of particle-grazing zooplankton and attached benthos in the marina. Hence, while there is some reason for concern that the groundwater leakage into the marina shall boost total nitrogen levels above the State Water Quality Limits for marina embayments, it is not expected to result in pollution sources of "undesirable aquatic life" or cause "objectionable color or turbidity". The reasons that these pollutant effects are unlikely in this specific case are summarized as follows:

1. The limiting micro-nutrient for plant growth in the marina water will be phosphorus, and its levels in the groundwater aquifer as atomic ratios relative to nitrogen show that most of the nitrogen loading as nitrate will not be available or converted to plant biomass because of this phosphorus limitation.

2. The physical characteristics of the marina-- very shallow depth of about 10 ft. (3 m) on average, designed parallel long-axis orientation to the prevailing tradewinds, non-stratified salinity and density conditions generally, and high exchange rates (9 to 20% daily exchange, or 5 to 11 day residence times, assuming complete wind and tidal mixing) -- are a significant physical dispersal mechanism to the groundwater nutrient loading.

3. Accumulated biomass from algal growth in marina waters from the groundwater nutrient loading will be partly controlled by populations of particle-grazing zooplankton and benthic animals such as sponges, tunicates, barnacles etc.; however, it is not possible to quantitatively predict <u>a priori</u> how much biotic control can be exerted relative to physical dispersal, for example. Since the marina is so shallow and expected to be very well mixed vertically, no sinking losses from the system are anticipated.

In the worst case scenario for rather brief durations (few days to perhaps a week), one could expect that during severe rainstorms with calm winds, which would allow stratification of marina water and inject heavy silt loads, algal blooms could occur in the most poorly flushed inner basins (Figure 4 areas A, G, H). However, a return to "normal" tradewind and tidal flushing conditions should enable adequate dispersal of any algal blooms to conditions like coastal waters.

Signed Jed Hirota

Jed Hirota, Ph.D.

APPENDIX 4

TSUNAMI EFFECTS

Tsunami Effects
on the
Ewa Marina Community Development

Prepared for

M.S.M. & Associates
926 Bethel Street
Honolulu, Hawaii 96813

Prepared by

Moffatt & Nichol, Engineers
250 W. Wardlow Road
Long Beach, CA 90807

March 20, 1986

TSUNAMI EFFECTS

General

The Hawaiian Islands are subject to tsunamis generated around the rim of the Pacific Basin. Fifteen of the 85 tsunamis that have been observed in Hawaii since 1813 have resulted in significant damage. Between 1946 and 1978, four significant tsunamis have been measured in the Ewa Beach area, as follows:

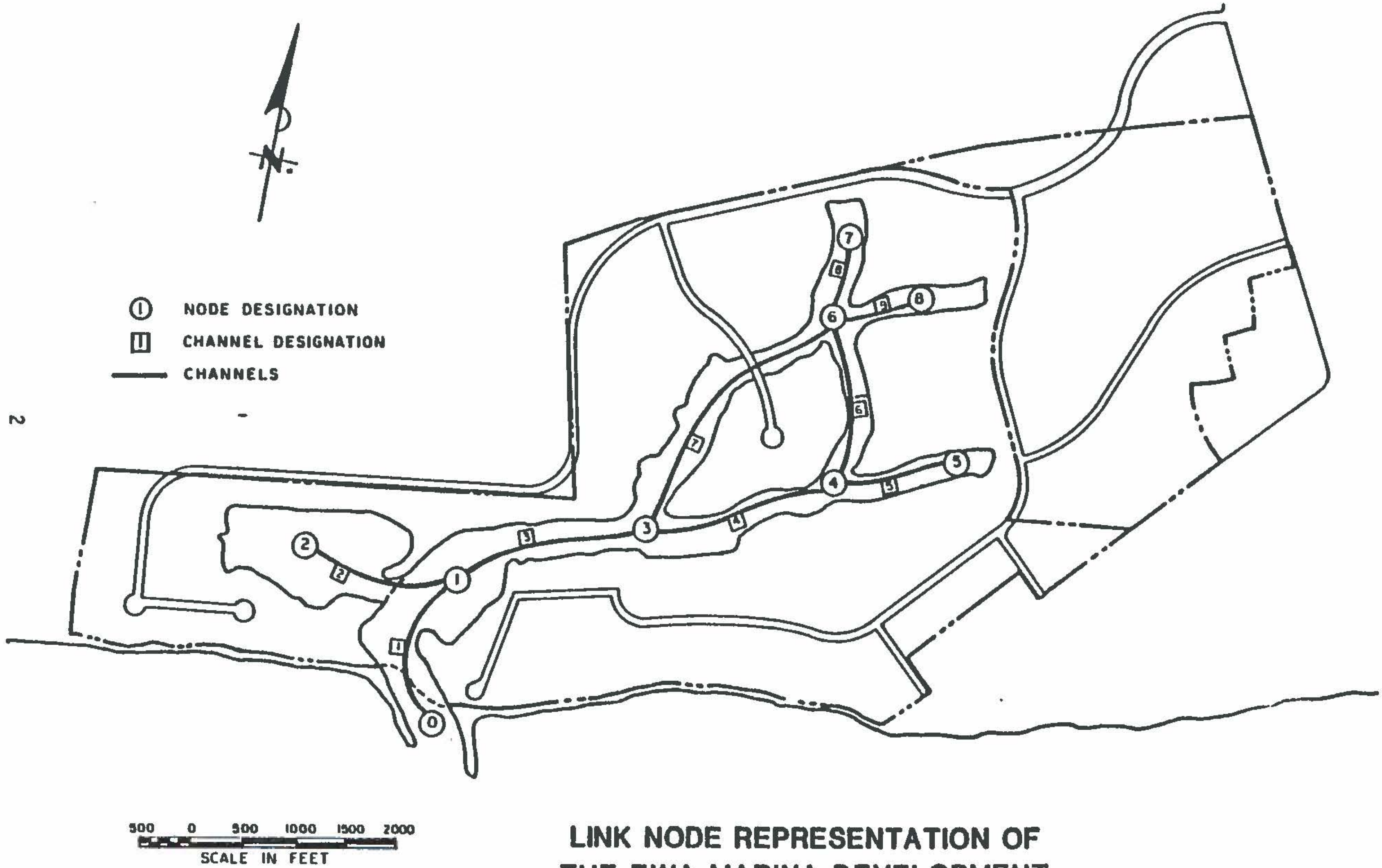
Year	Origin	Runup (ft above MLLW)
1946	Aleutian Islands	3
1952	Kamchatka Peninsula	5
1957	Aleutian Islands	9
1960	Chile	9

Runup is the elevation of the high water mark left by a tsunami. According to observers' reports, the tsunamis listed above did not produce a bore along the Mamamla Bay shoreline, but appeared as a rapid rise and fall of sea level. An urbanized area close to the shore could therefore suffer damage due to inundation, but probably not structural failures caused by impact forces.

Flood level maps for the Hawaiian Islands have been prepared by the Corps of Engineers. For most of the coastline, including the Ewa area, the controlling criterion is a tsunami event of 100-year return period. The maximum runup elevation for the existing conditions does not exceed +9 feet above MLLW along the coast. However, resonance characteristics of the proposed marina waterways may tend to amplify water level fluctuations near the ends of the finger channels.

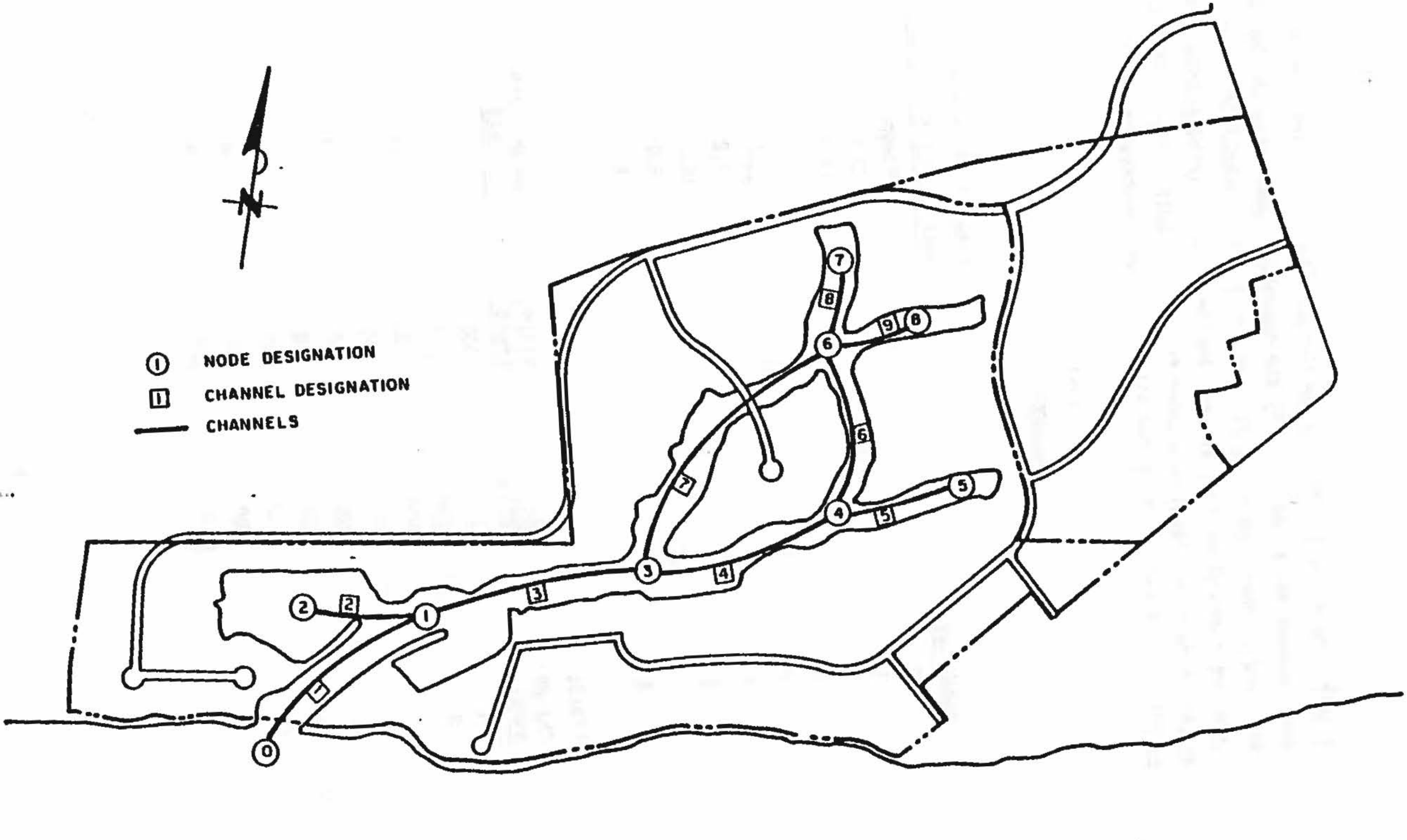
Methodology

Numerical computations were made using a link-node hydrodynamic model of the proposed Ewa Marina Community development. The configuration of the model is shown in Figure 1 for the east entrance location and in Figure 2 for the west entrance location. Circled numbers in the figures



LINK NODE REPRESENTATION OF
THE EWA MARINA DEVELOPMENT
(EAST ENTRANCE)

FIGURE 4



LINK NODE REPRESENTATION OF
THE EWA MARINA DEVELOPMENT
(WEST ENTRANCE)

FIGURE 2

identify the nodes in which water surface elevations were computed. The links between the nodes identify the channels. Surface areas for the nodes and channel dimensions for the links are indicated in Table 1. These areas and dimensions are applicable to both marina systems. Water depths at mean sea level were used for the channels. The roughness coefficient (Manning's "n") for all of the coral-excavated channels was

Table 1

LINK-NODE DIMENSIONS

NODES:

Node Number	Water Surface Area at Mean Sea Level (Acres)
0	Ocean
1	27.0
2	18.4
3	27.2
4	11.3
5	3.2
6	15.5
7	5.0
8	3.0

LINKS:

Channel Number	Length (feet)	Width (feet)	Water Depth (feet)
1	1500	400	16
2	100	200	11
3	2400	350	11
4	1600	300	9
5	1200	100	9
6	1500	200	9
7	2600	300	9
8	800	300	9
9	1100	185	9

taken as 0.030. The value of Manning's "n" was taken from Chow (1959) for representative "n" values for channels cut in rock. Table 5.6 in Chow (1959) gives values of "n" that range from 0.025 for smooth cuts to 0.050 for rough cuts. For the Ewa marina channels with cut coral walls, the "n" value of 0.030 is considered conservative and may take into account future siltation that would make the channel bed less rough. Figure 3 is a typical section of the channels used for calculating water surface areas for various water elevations.

The forcing function used at the marina entrance was the tide gage record from Honolulu Harbor during the 1960 tsunami. The maximum water elevation at that location was 4.1 feet above MLLW. The run-up at Honolulu Harbor during the 1960 tsunami was 5 feet above MLLW. The run-up at Ewa Beach for the same tsunami was measured at 9 feet above MLLW. Thus, the runup elevation at Ewa Beach was amplified by a factor of 1.8. This amplification factor was directly applied to the forcing function at Ewa Beach for computing water elevations in the marina channels. The amplified tide gage record for Ewa Beach is shown in Figure 4.

Results

Plotted water surface elevations for each node are illustrated in Figures 5 through 8. These plots indicate the elevations within the marina during an occurrence of a tsunami similar to the 1960 event. The plots are applicable to both marina systems. Figures 9 and 10 are tsunami inundation maps for the two marina systems. The elevations indicated on these maps are the maximum computed water surface elevations within the Ewa Marina. The maximum elevation computed is +11.5 feet above MLLW for the upper end of the marina. Along the open coast, maximum tsunami runup elevations measured from debris lines would likely be higher than the +8.0 feet above MLLW water surface elevation computed from the model.

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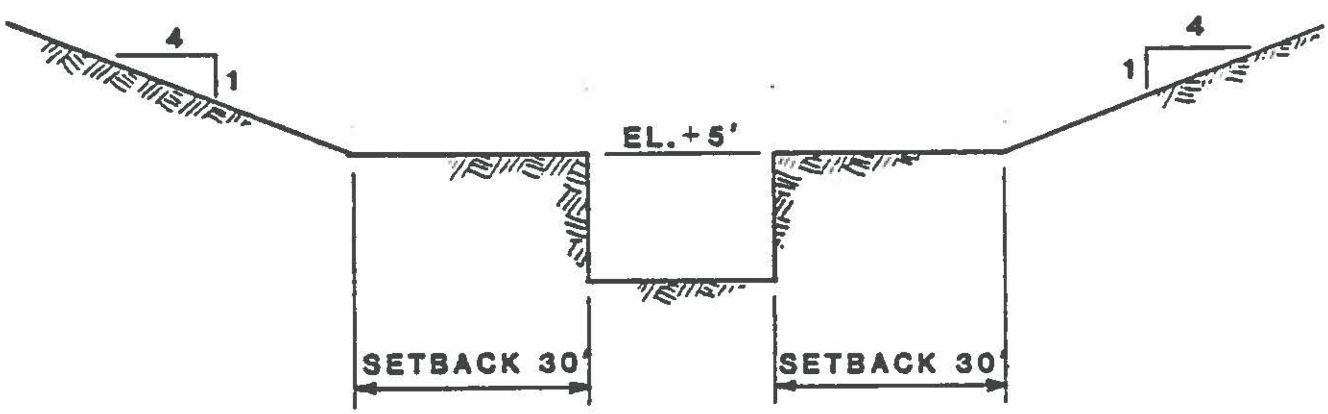
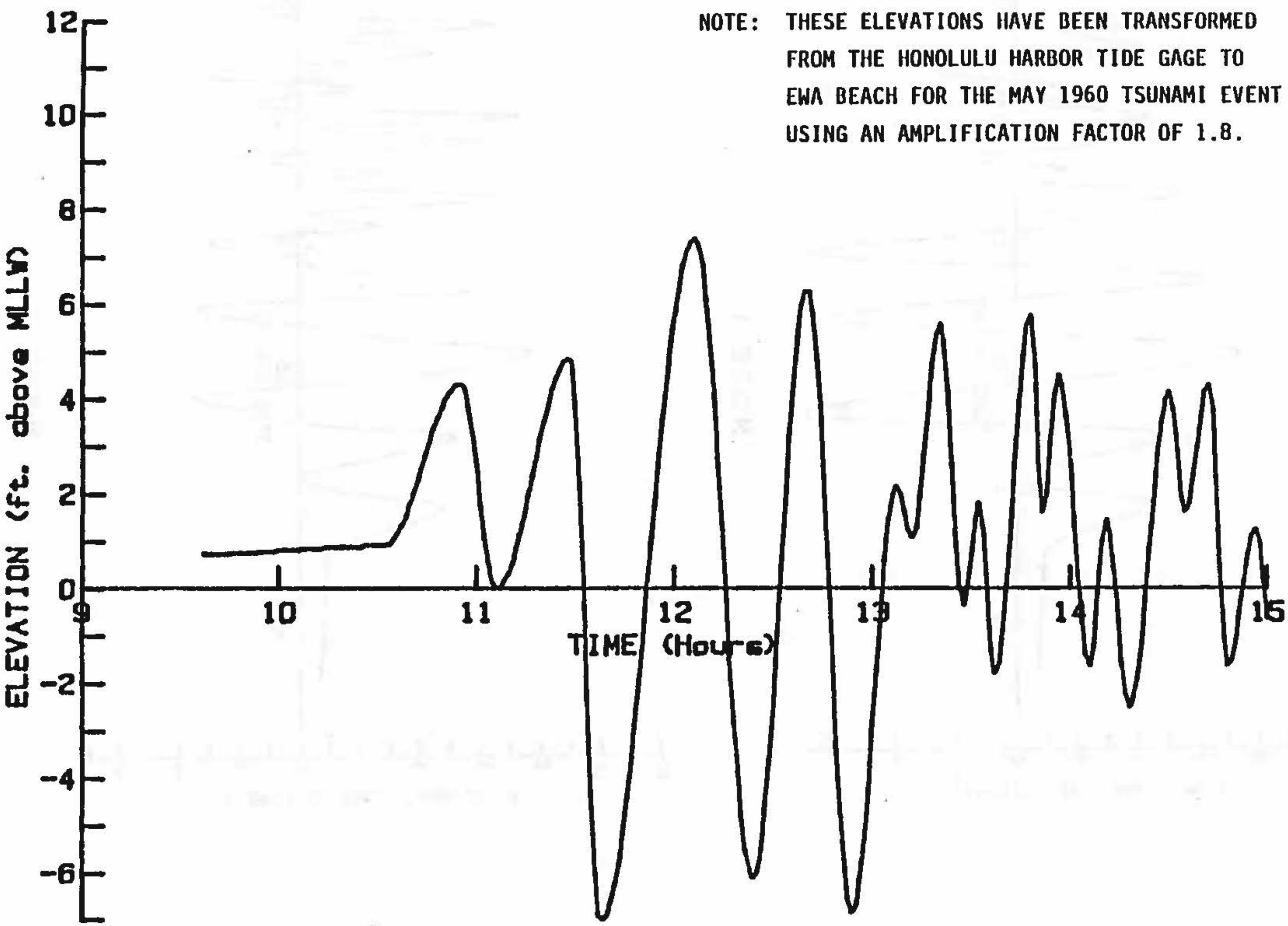


NOTE: DATUM IS MLLW

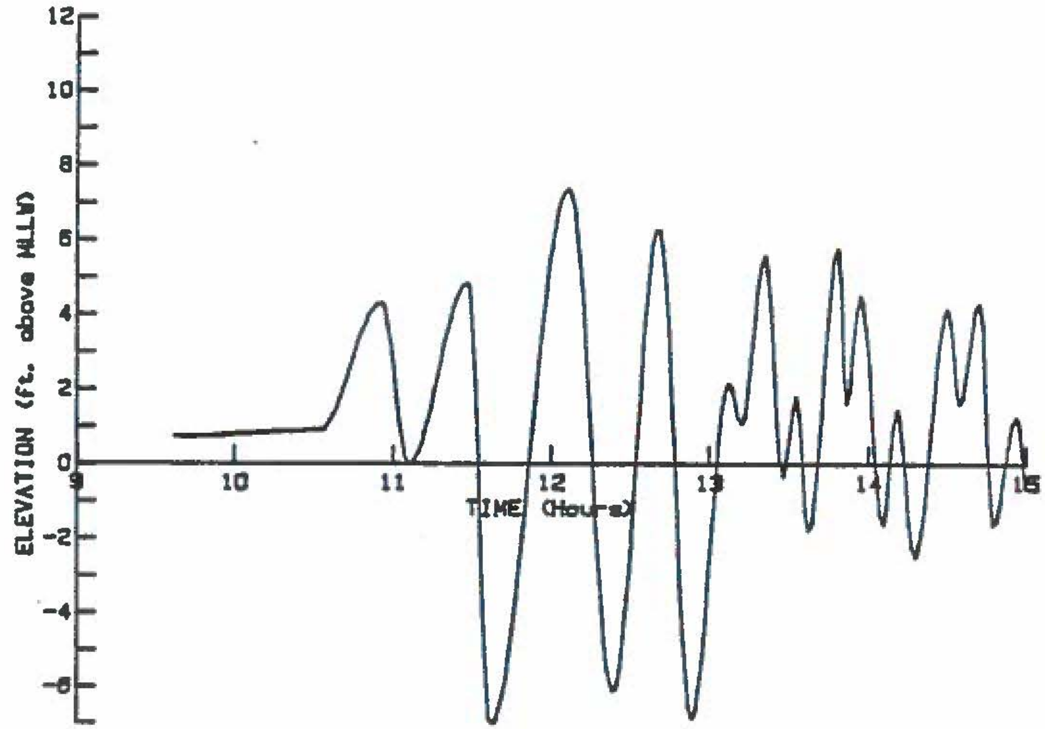
TYPICAL SECTION OF EWA MARINA CHANNELS
FOR LINK-NODE MODEL

FIGURE 3

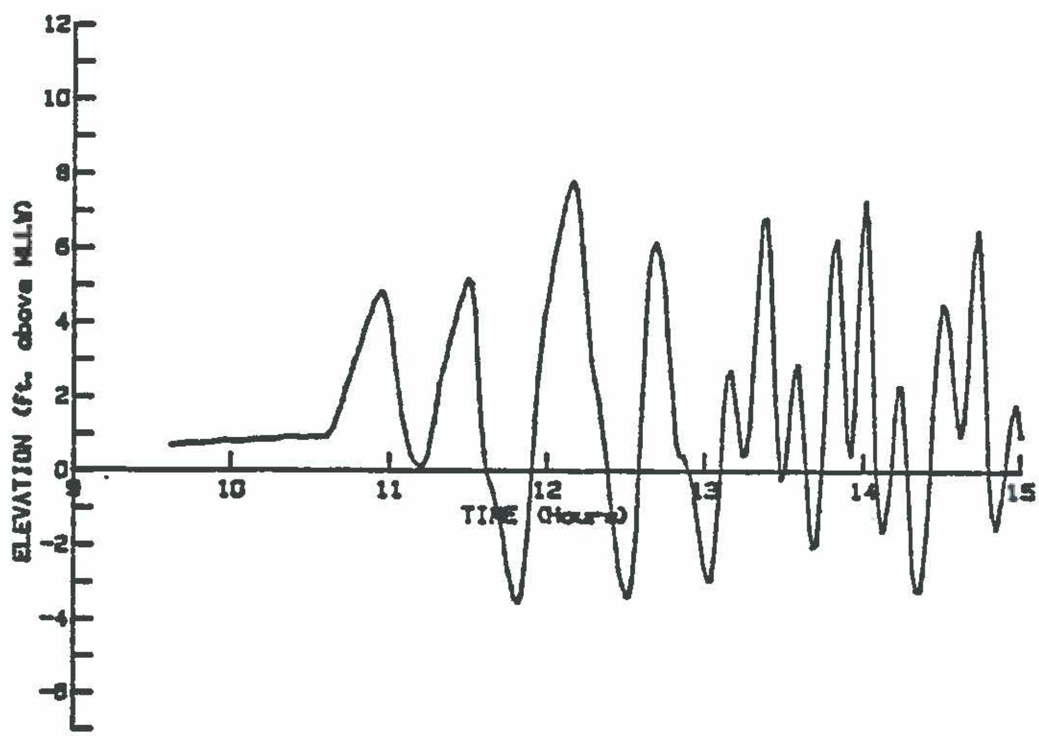


INITIAL WATER SURFACE ELEVATION AT MARINA ENTRANCE
(NODE Ø)

FIGURE 4



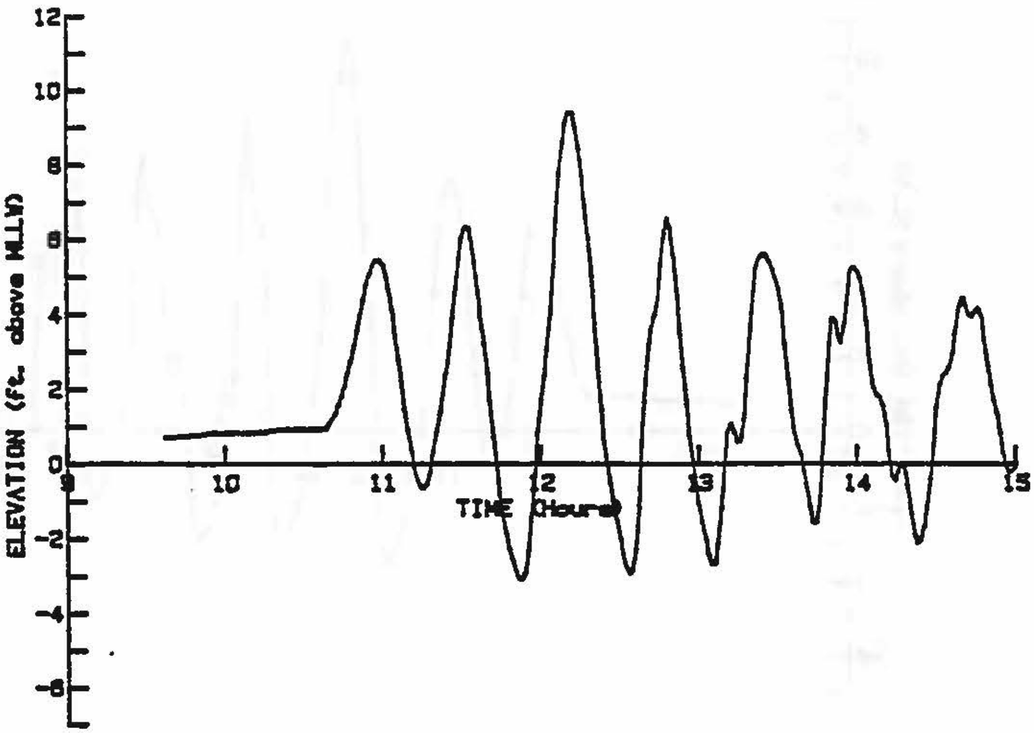
NODE 1



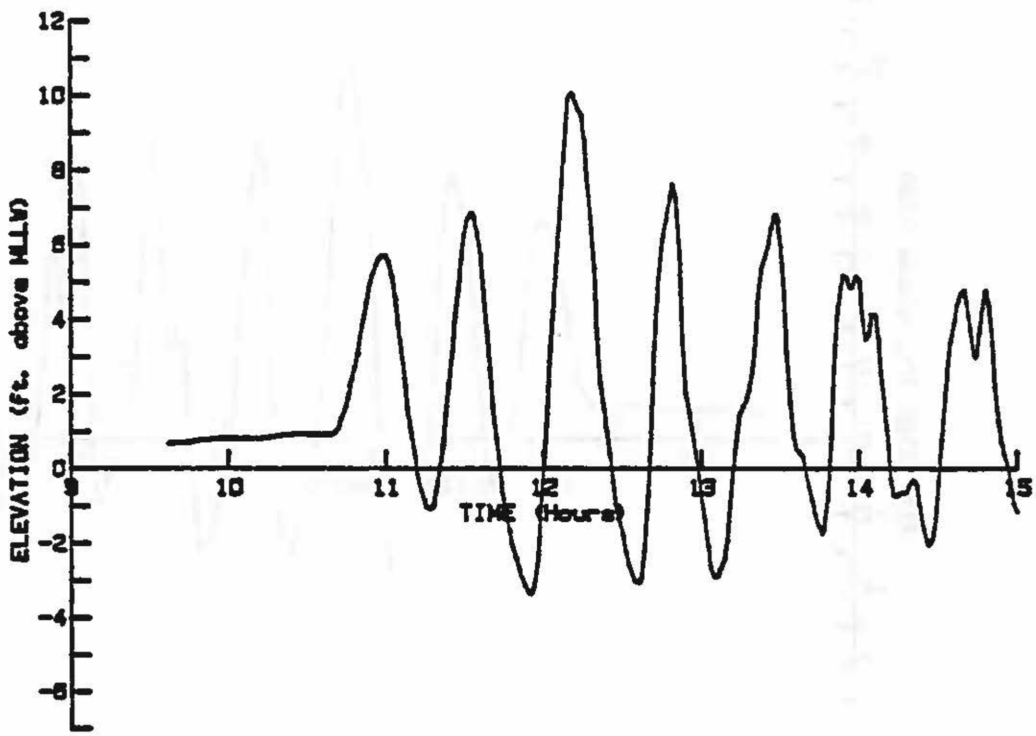
NODE 2

WATER SURFACE ELEVATIONS FOR NODES 1 AND 2

FIGURE 5



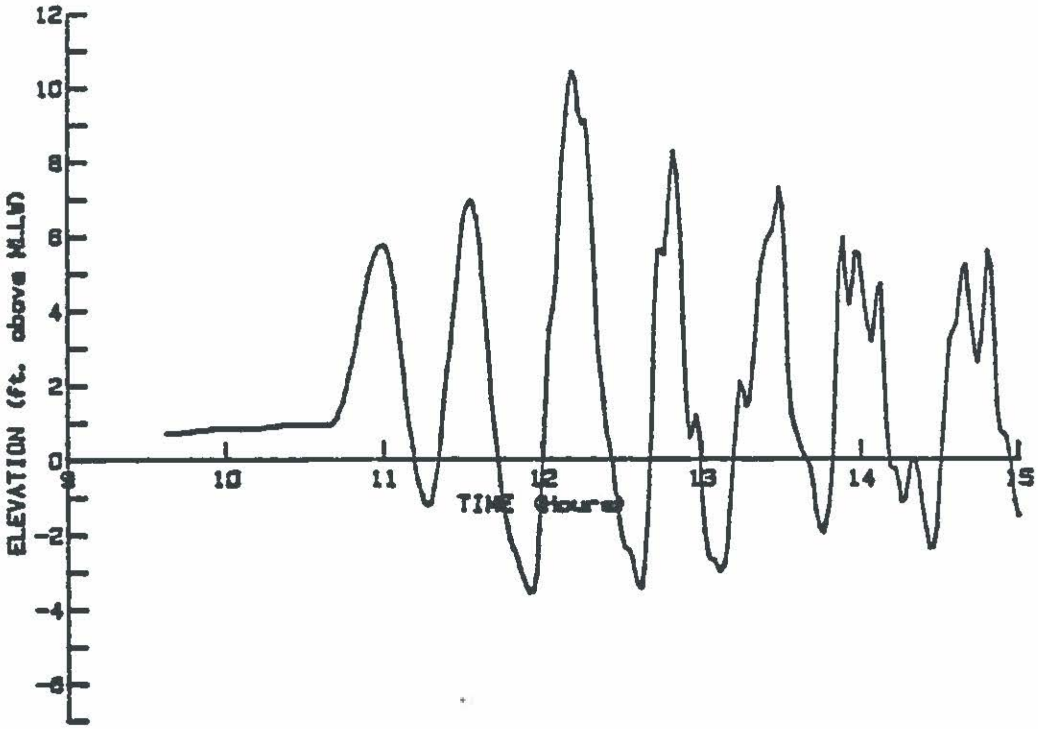
NODE 3



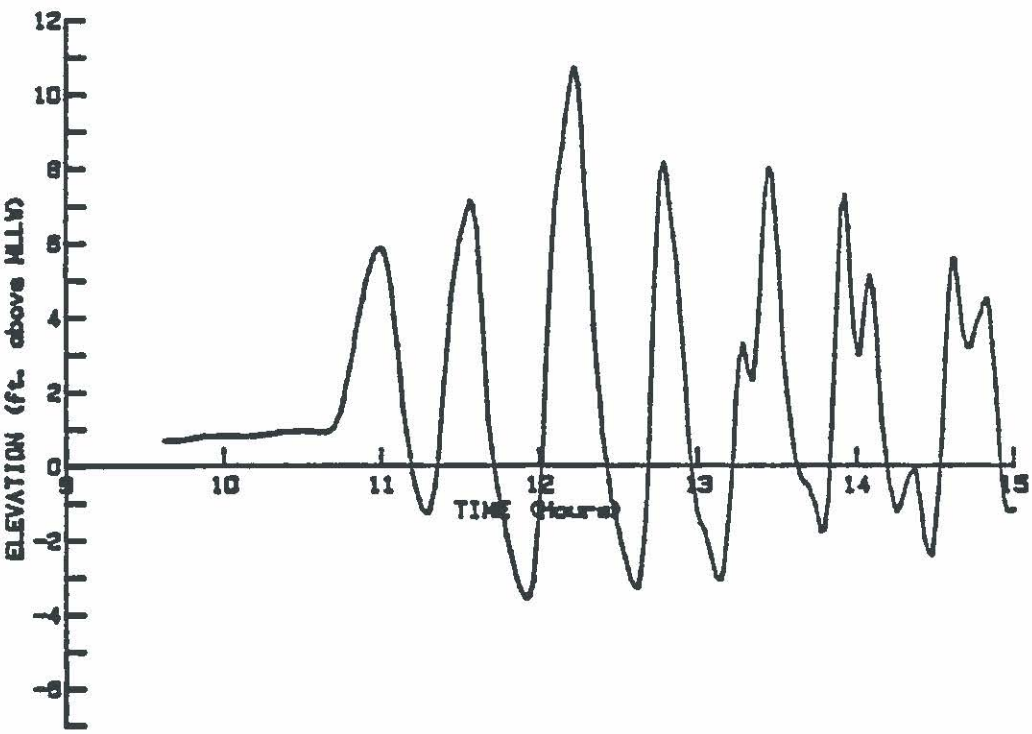
NODE 4

WATER SURFACE ELEVATIONS FOR NODES 3 AND 4

FIGURE 6



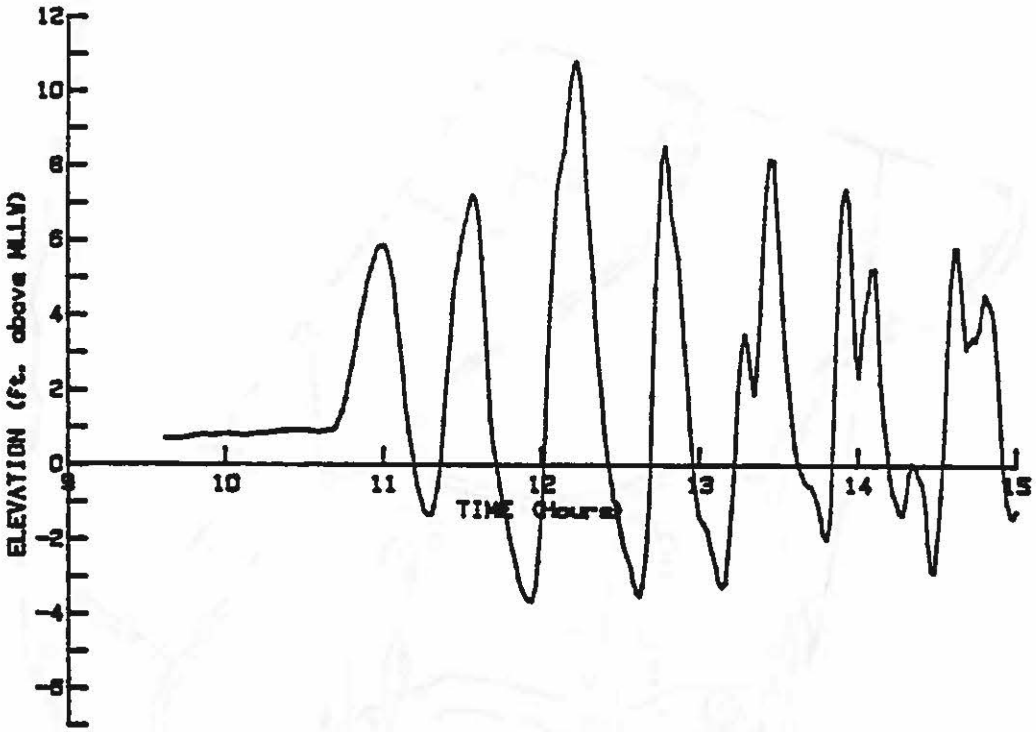
NODE 5



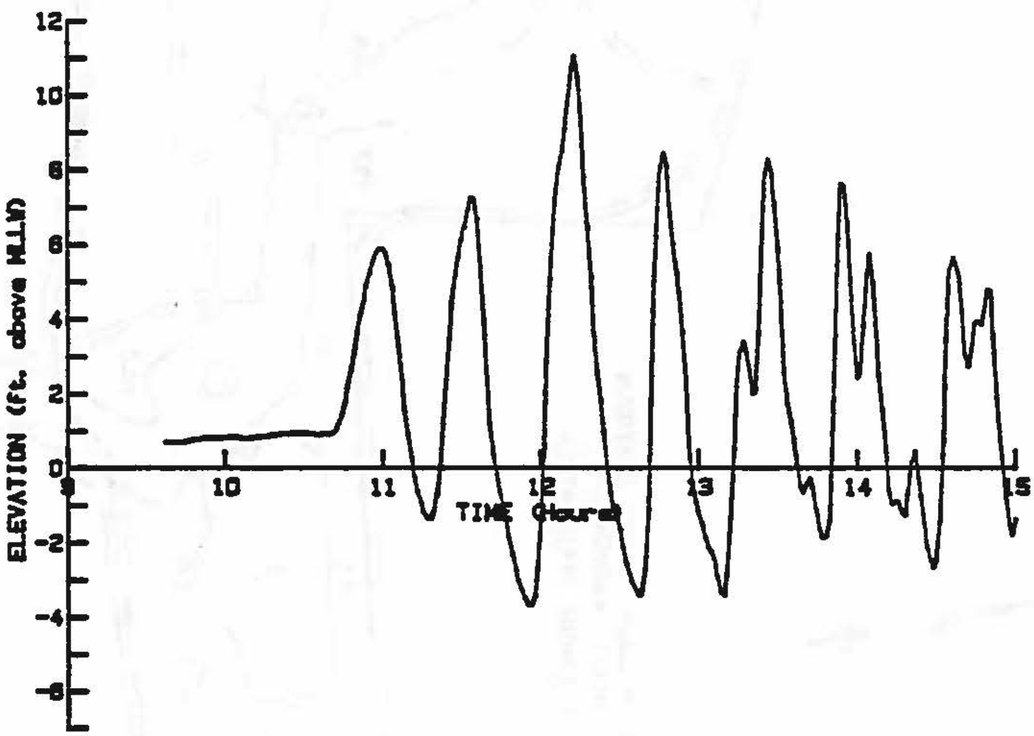
NODE 6

WATER SURFACE ELEVATIONS FOR NODES 5 AND 6

FIGURE 7



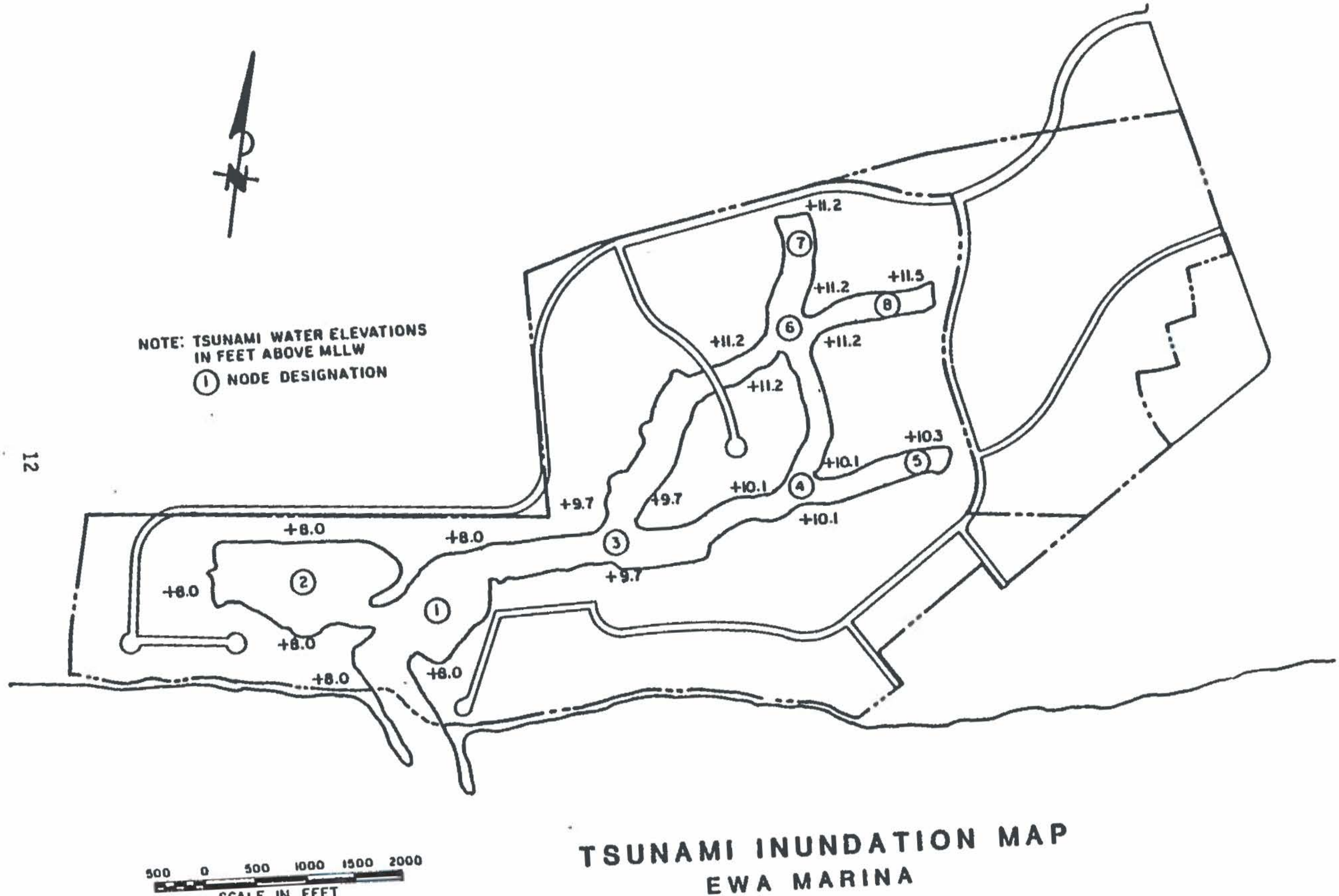
NODE 7



NODE 8

WATER SURFACE ELEVATIONS FOR NODES 7 AND 8

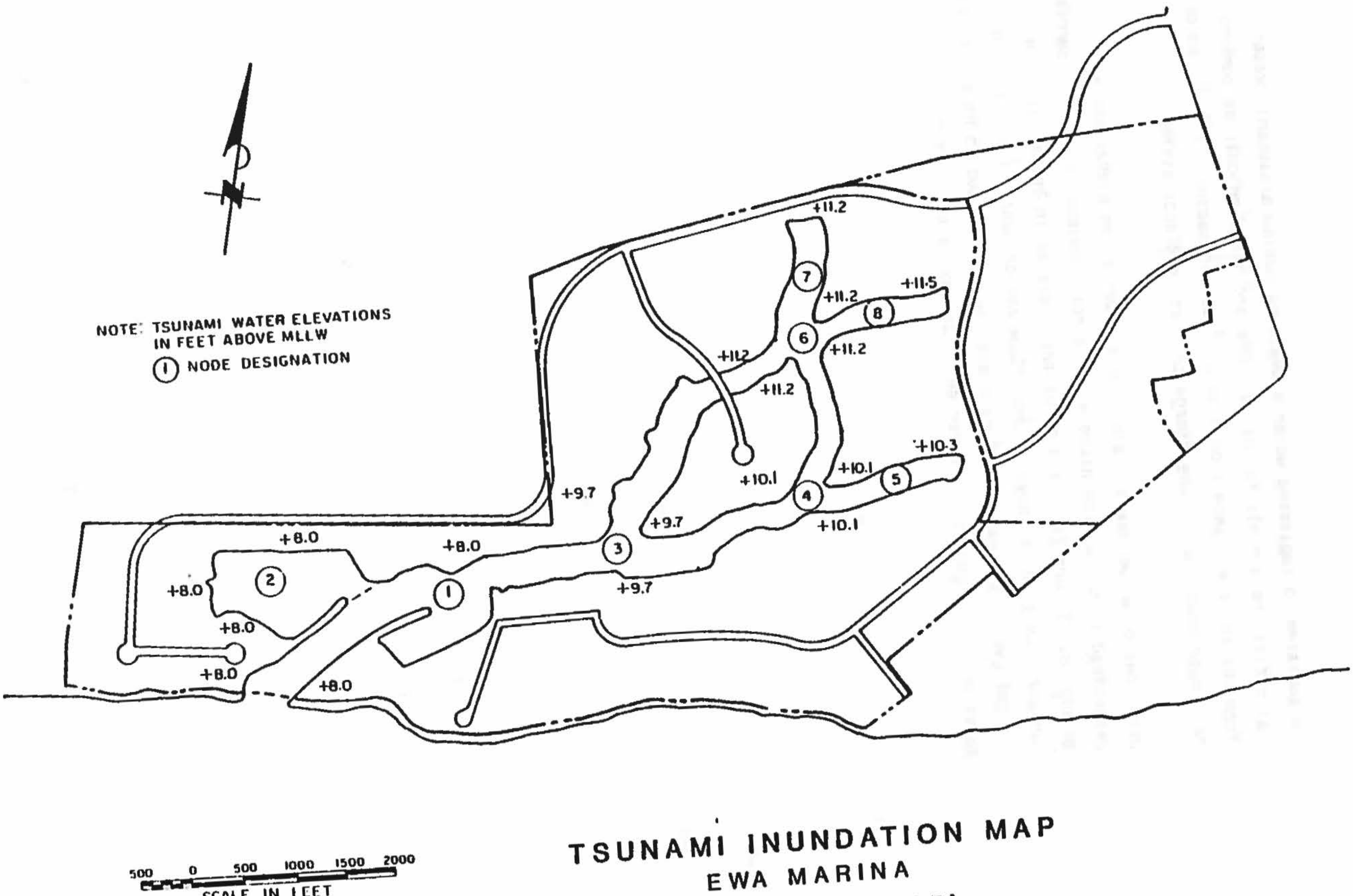
FIGURE 8



NOTE: TSUNAMI WATER ELEVATIONS IN FEET ABOVE MLLW
1 NODE DESIGNATION

TSUNAMI INUNDATION MAP
EWA MARINA
(EAST ENTRANCE)

FIGURE 3

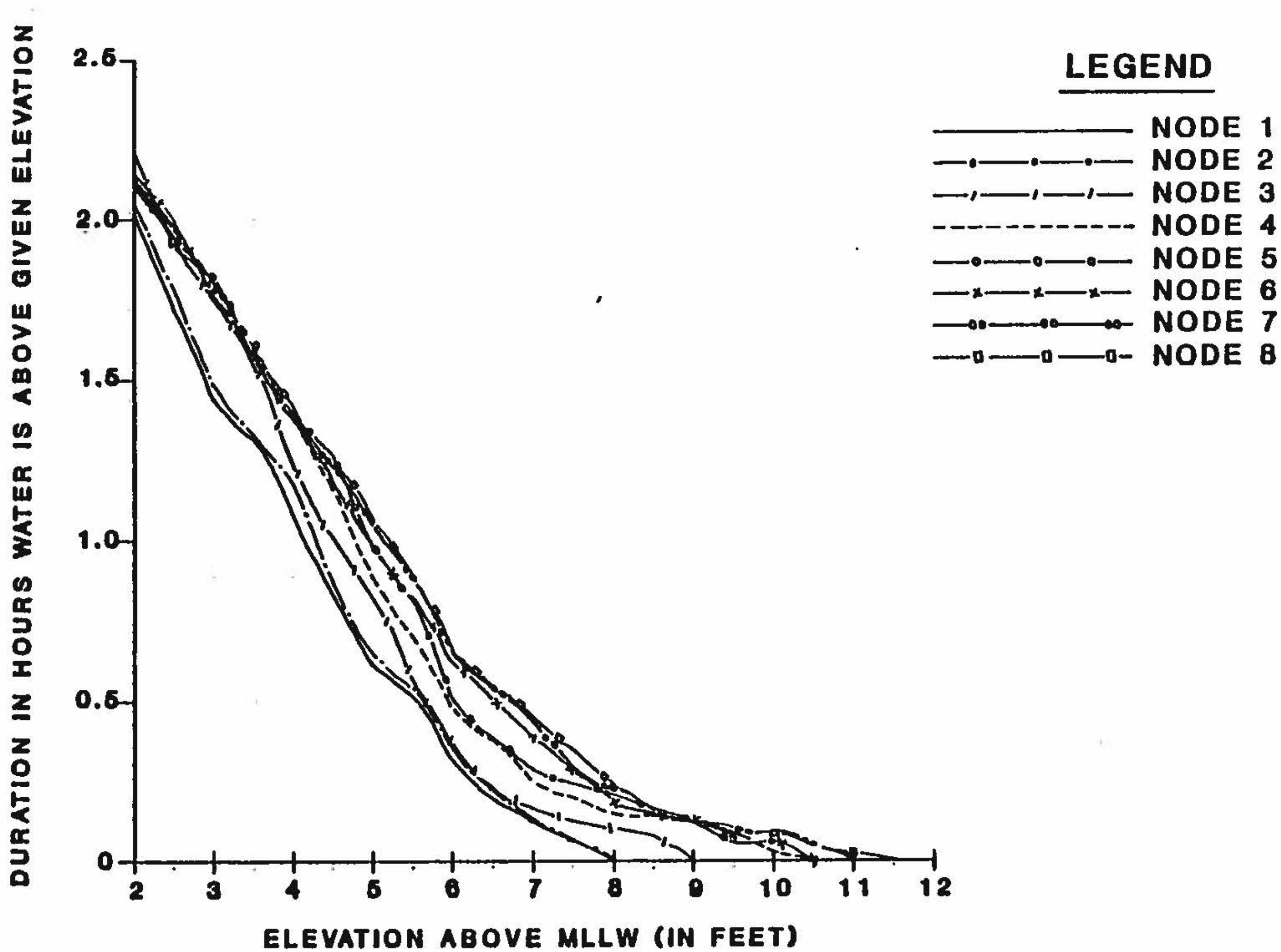


TSUNAMI INUNDATION MAP
EWA MARINA
(WEST ENTRANCE)

FIGURE 10

In addition to amplified water elevations during a tsunami, water velocities are greatly increased. Ebb and flood velocities computed from the analyses range from 0 to 11 feet per second. Velocities of this magnitude could cause damage to boats and dock systems.

Durations of water surface elevations above given elevations were determined from the time-history plots for each node shown in Figures 5 through 8. Figure 11 is a plot of the duration in hours which the water surface elevation is above +2 feet MLLW and greater. For a similar tsunami event, the water surface elevation is expected to be at +10 feet above MLLW or higher for a duration of approximately 50 minutes.



DISTRIBUTION OF TIME THAT WATER LEVEL IS AT OR ABOVE A GIVEN ELEVATION

FIGURE 11

APPENDIX 5

MARINE BENTHIC SURVEY

AECOS 451

QUANTITATIVE AND QUALITATIVE BIOLOGICAL SURVEYS ALONG PROPOSED CHANNEL ALIGNMENTS FOR THE EWA MARINA COMMUNITY DEVELOPMENT, EWA, OAHU, HAWAII

Prepared For:

Dames & Moore
1144 10th Avenue, Suite 200
Honolulu, Hawaii 96816

Prepared By:

AECOS, Inc.
970 N. Kalaheo Ave, Suite A300
Kailua, Hawaii 96734

April 1986

TABLE OF CONTENTS

INTRODUCTION

The Ewa Marina Community is a proposed community development project on nearly 735 acres located along the south shore of O`ahu between `Ewa Beach and Barbers Point Naval Air Station. This development would include construction of 4,850 residences for 15,000 people, nearly 67 acres of commercial development, and a 115 acre waterway providing slips for 1,600 boats (Dames & Moore, 1985). Boat access to the proposed marina would require the dredging of a channel across the broad, fringing reef off the `Ewa coastline. The channel would be 122 meters (400 feet) wide and approximately 880 meters (2,900 feet) long. Channel depth would be 6 meters (20 feet) at its seaward end, shoaling to 4 meters (12 feet) deep near shore where the channel would connect to waterways dug out of the `Ewa Plain on the project site.

Several marine surveys have been conducted in conjunction with the environmental assessment for the Ewa Marina Community project (Hawaii Marine Research, 1979; AECOS, 1980; Dames & Moore, 1984). In addition, several pertinent biological studies not related to the project but conducted in the same general reef area have been conducted in the past (Reed, 1974; State Division of Fish & Game, 1975; Dollar, 1979; AECOS, 1981). The present survey was initiated in order to provide a biological assessment of the reef flat and reef margin directly along two proposed alternative alignments.

METHODS

The present study entailed two days of surveys and transects (February 28 and March 1, 1986) on the reef off the Ewa Marina Community project. The survey areas were selected to be representative of two potential channel alignments for the proposed marina (see Dames & Moore, 1985). These alignments have been designated as the "East Channel Alignment" and the "West Channel Alignment" and are 300 yards apart (center line to center line). The East Channel Alignment would be located at essentially Keku Point. Quantitative transects were conducted by Dr. R.E. Brock; Eric Guinther made qualitative observations.

A total of nine quantitative transects were undertaken (see Figure 1) between 50 and 900 meters (160 to 3000 feet) from the shore. These ranged in depth between 1 and 8 meters (3 to 25 feet). Each transect was 20 meters (65.62 feet) long. All transects were run parallel to shore (across the channel alignments) at locations deemed to be representative of the different reef environments to be impacted directly by channel dredging. Prior to initiating field work, an interpretation of bottom types was undertaken using an enlarged color photograph of the reef area. Decisions as to general locations for transecting and navigation while in the field were based on this map (Figure 1). Bottom types were interpreted and coded by the methods and classification system developed for the Oahu Coral Reef Inventory atlas (AECOS, 1981). Bottom types in this particular area had not been previously interpreted for the OCRI atlas, probably because turbid water conditions at the time aerial photographs used in that project were taken obscured bottom features. Reportedly, exceptionally turbid water is typical for this leeward reef environment (Sea Engineering Services, Inc., 1978; AECOS, 1980)

In the absence of markers on or off the shore to delineate the proposed channel alignments, bottom features were used to navigate on the reef and locate survey positions. This method proved moderately difficult in practice because water depth generally exceeded 3 meters (10 feet), although water clarity was reasonably high on the days selected for the surveys. Had these waters been turbid, positioning of the transects relative to the map would have been difficult or impossible with any degree of certainty. Marine biologists from DLNR accompanied the survey team for the purpose of fixing station locations relative to landmarks so that the stations could be resurveyed at a later date. Even this method of fixing positions proved difficult at many of the sites because few suitable landmarks are visible from this reef area.

The proposed East Channel Alignment was readily determined in the field. Comparison of our bottom-type map with the survey conducted by Edward K. Noda and Associates (1985) and with other maps prepared by Dames & Moore (1985) showed that this alignment extended from a notch in the coastline immediately west of Keku

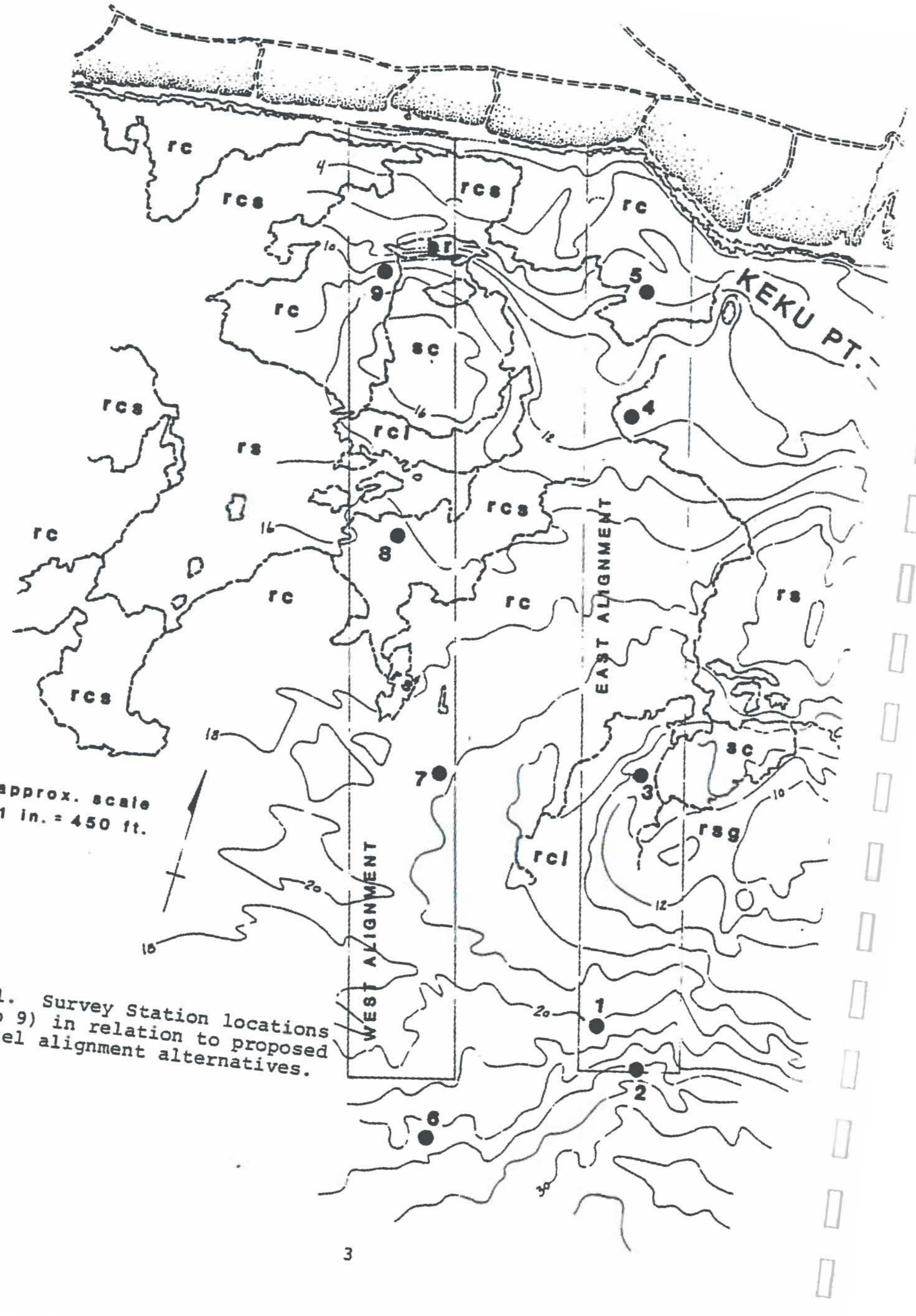


Figure 1. Survey Station locations (1 to 9) in relation to proposed channel alignment alternatives.

Point to and beyond a large sand patch located 600 meters (2000 feet) off Oneula Beach Park. The sand patch and the shoreline notch, both of which could be seen from a boat across the required distances, were used to fix the proposed alignment for positioning of the survey stations.

The alternate West Channel Alignment proved somewhat more difficult to establish in the field because neither a distinct shoreline feature nor unique bottom features far offshore existed. This alignment would be parallel to, and 300 meters (900 feet) west of the East Channel Alignment. At the shore, the channel center line would be near the western end of a small beach (see Figure 1). The alignment would then pass seaward along the western edge of a large sand bottom area located approximately 200 meters (600 feet) offshore. The latter area was located and a temporary marker buoy set out. Subsequent station locations were determined by aligning a fixed point on the shore behind the beach with the marker buoy, and noting depth and distance offshore. However, the fact that the "outer marker" (the temporary buoy) was located relatively close to the shore introduced a degree of uncertainty in locating the outermost stations relative to the centerline of the West Channel Alignment.

A qualitative reconnaissance was made at each station by swimming (SCUBA and skin diving) and recording bottom type and benthic community structure. These qualitative assessments enabled a determination of the representativeness of each transected location, and provided an overall assessment of the marine benthic communities present along each alignment. The quantitative transects included a visual enumeration of fishes, counts along the transect line laid along the bottom, and cover estimates in benthic quadrats. Finally, the immediate area around each transect was surveyed qualitatively to record the presence of any species not encountered in the transects.

Quantitative transects were conducted in the following manner. Immediately following site selection, a visual fish census was undertaken to estimate the abundance of fishes. These censuses were conducted within a 20 x 4 meter corridor and fishes within this area to the water surface were counted. Fish abundance and diversity is often related to small-scale topographic relief over short linear distances. A long transect may cross a number of topographical features (e.g., coral mounds, sand flats, and algal beds), thus sampling more than one community and obscuring distinctive features of individual communities. To alleviate this problem, a short transect (20 m in length) has proven adequate in sampling many Hawaiian benthic communities (Environmental Consultants, Inc., 1975; Bienfang and Brock, 1980).

A diver equipped with SCUBA, transect line, slate and pencil would enter the water, count and note all fishes in the prescribed area (method modified from Brock, 1954). The 20 meter transect line was paid out as the census progressed, thereby avoiding undue underwater activity which could frighten wary fishes in the area.

Besides frightening wary fishes, other problems with the visual census technique include the underestimating of cryptic species such as moray eels (family Muraenidae) and nocturnal species, such as squirrelfishes (family Holocentridae), aweoweo (family Priacanthidae), etc. This problem is compounded in areas of high relief and coral coverage affording numerous shelter sites, circumstances which were not present at most of the Ewa Marina survey stations. Species lists and abundance estimates are more accurate for areas of low relief, although some fishes with cryptic habits or protective coloration (e.g., nohu, family Scorpaenidae; the flatfishes, family Bothidae) might still be missed. Obviously, the effectiveness of the visual census technique is reduced in turbid water (water clarity was good during the present surveys) and species of fishes which move quickly and/or are very numerous may be difficult to count. Additionally, bias related to the experience of the diver conducting counts should be considered in making any comparisons between surveys. As noted by Brock (1982), the visual census technique, in spite of these drawbacks, probably provides the most accurate nondestructive assessment of diurnally active fishes presently available.

Figure 2. SCUBA diver on transect line at Station 1.

Following the assessment of fishes, an enumeration of epibenthic invertebrates (excluding corals) was undertaken using the same transect line as that established for fish counts (see Figure 2). Exposed invertebrates (essentially those seen without disturbing the substratum; e.g., turning over loose boulders) generally greater than 2 cm in one dimension were censused in a 20 x 4 m area. As with the fish census technique, this sampling methodology is quantitative for only a few invertebrate groups, e.g., some echinoids, holothurians, and larger crustaceans. Most reef invertebrates (other than corals) are cryptic or nocturnal in their habits making an accurate assessment of their numbers in areas of great topographical relief very difficult. This, coupled with the fact that the majority of these cryptic invertebrates are small, necessitates the use of methodologies beyond the scope of this survey (e.g., see Brock and Brock, 1977; Guinther and Bartlett, 1986). Recognizing constraints on time and survey scope, the invertebrate censusing techniques used here attempted only to assess those few macroinvertebrate species that are diurnally conspicuous.

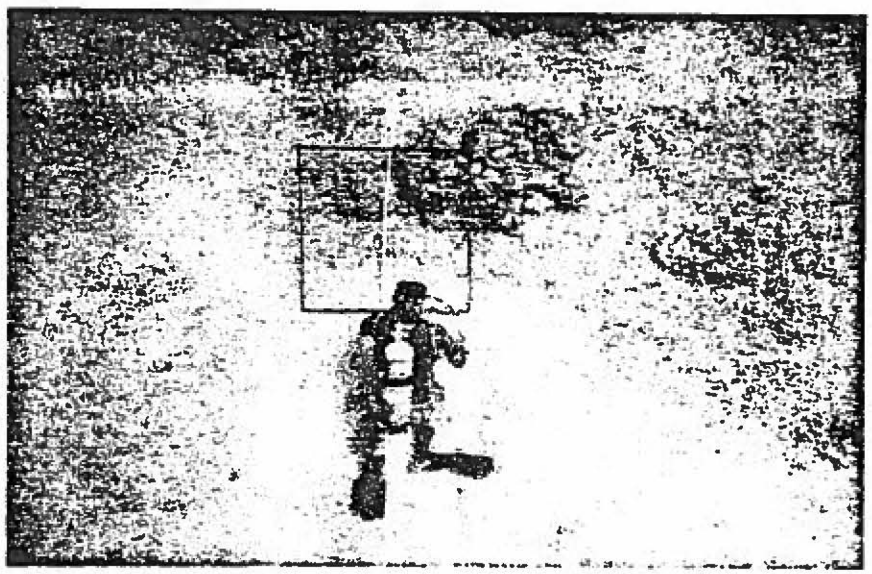


Figure 3. SCUBA diver on transect at Station 6 with quadrat frame one meter on a side.

Exposed sessile benthic forms such as corals, macrothalloid algae, sponges, etc. were quantitatively surveyed using quadrats and the point-intersect method (see Figure 3). The point-intersect technique only notes the species of organism or substratum type directly under a point. Along the previously set fish transect line, 40 such points were assessed (once every 50 cm). These data have been converted to percentages. Quadrat sampling consisted of recording benthic organisms, algae and substratum present as a percent cover in five one-meter-square frames placed at 5-meter intervals along the established transect line (at 0, 5, 10, 15, and 20 meters).

Simple methods of data reduction and analysis have been used and are described where met with in the text. Diversity (H') is calculated as described by Pielou (1966):

$$H' = -\sum p_i(\ln p_i)$$

where p_i is that proportion of the individuals censused belonging to species i. This is the Shannon-Wiener Index.

RESULTS

GENERAL DESCRIPTION

The reef which extends off the `Ewa Plain is exceptionally broad by comparison to most such features around the Island of O`ahu. However, the depth across the reef flat, which varies generally between 2 and 4 meters (6 to 12 feet), suggests this reef is an erosional remnant of the extensive, geologically ancient, emergent reef which forms the `Ewa Plain. Recent reef growth on the submarine portion of this feature has only marginally maintained growth against natural erosive processes. However, the reef margin is shallow, generally, relative to mid-reef areas.

The shoreline here is typically an eroded, limestone bench (lm3) feature (see Wentworth, 1939), but sand shoreline (sb, beach) does occur along some sections: off Oneula Beach Park (east of Keku Point), a small segment of the shore west of Keku Point, and "Officers Beach" (part of Nimitz Beach) at Barbers Point NAS to the west. Immediately off the shore, hard bottom (rc) predominates in nearly all areas, although this bottom may be covered by a thin layer of sand held in place by benthic algal turf and small mussels, or the bottom might be a mixture of veneered limestone, outcrops, and sediment over limestone (rs, rcs).

Hard bottom areas (rc, rcl) predominate across much of the reef flat, although most areas, both behind the reef margin and off the front face of the reef, include a considerable amount of sand and silty-sand present as a veneer which covers the limestone bottom or occurs in pockets, depressions, grooves, or over broad areas to a thickness of a few inches to a few feet (Noda, 1985). The upper reef face (directly seaward of the relatively shallow reef margin) is cut by shallow grooves running down-slope (rcg, rgs). At depths of 15 to 30 feet, the ridges between grooves extend seaward as low features separated by more or less smooth bottom of limestone or sand over limestone. Some essentially all sand bottom areas (sc) are present, and noted in the field to be large, sand-filled depressions.

STATION DESCRIPTIONS, EAST CHANNEL ALIGNMENT

STATION 1

Station 1 was established off the front of the reef at a depth of 6 to 7 meters (18 to 22 feet), approximately 800 meters (2600 feet) from shore. This station was conducted at a point that would mark the western edge of the proposed channel alignment at approximately the maximum project depth -- thus representing the outer margin of the proposed corridor to be dredged. The bottom here is mostly a featureless limestone plain with scattered depressions 0.5 to 3 m (1.5 to 10 feet) in diameter and

10 to 70 cm (4 to 28 inches) deep. These depressions are spaced from 0.5 to 5 m (1.5 to 16 feet) apart (Figures 4 and 5A). Sand and rubble forms a discontinuous veneer over the surface. East of the transect location (and within the proposed dredge corridor), low ridges extend more or less perpendicular to the reef margin, separated by sandy-bottom over limestone (Figures 5C and 5D). Although the bottom at this station has a relatively low seaward slope, immediately south of the transect, the bottom drops more steeply to depths exceeding 10 m (30 feet).

Dominant organisms on the bottom in this area are sponges (Iotrochota) and small anemones (Aiptasia). Algae are generally sparse; Codium edule, Asparagopsis taxiformis, and fine branching, calcareous forms (e.g., Jania) being the more common species. The dominant benthic organism in the transect at Station 1 is the alga, Codium edule, occurring in patches up to 25 cm (10 inches) in diameter. Corals present in the area include Porites lobata and Pocillopora meandrina; coverage is less than one percent. The maximum diameter of the Porites lobata heads is less than 1.5 m. Table 1 presents a synopsis of the benthic transect survey conducted at Station 1; a list of fishes censused is given in Appendix 1.

In the area of low ridges east of the transect, cover by low mounds of Porites lobata reaches perhaps 20% of the bottom -- considerably more than in the area of the transect. Consequently, it was decided to conduct a second transect in an area more typical of this type of bottom (see Station 2).

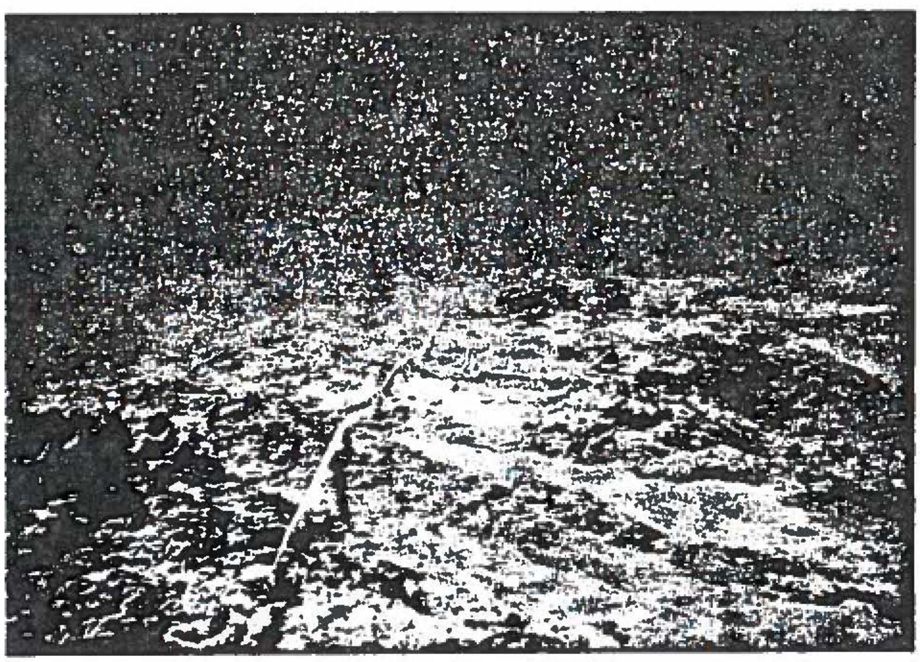


Figure 4. View of transect line and benthic community, Station 1.

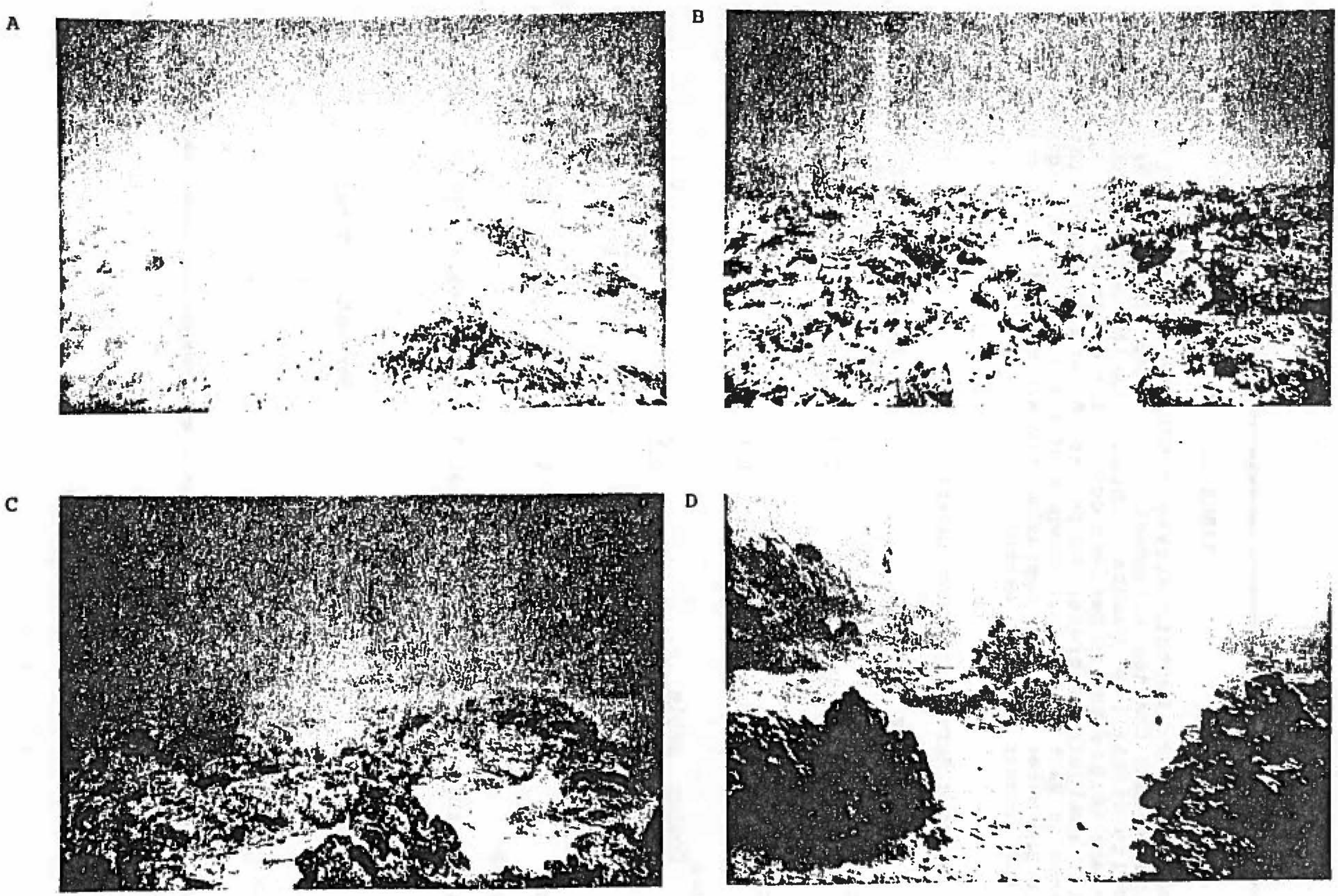


Figure 5. Variation in bottom type off the front of the reef at Station 1. A - Low relief, sandy bottom near transect. B - Low relief, limestone bottom. C - Moderate relief, limestone ridges with live coral (<u>Porites lobata</u>). D - Area of maximum relief, limestone ridges with live coral.

TABLE 1.

Summary of the benthic survey conducted at Station 1 on the proposed East Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth is approximately 6.1 m; mean coral coverage is 0.6 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata	2.5	0.5			
Pocillopora meandrina		0.1			
Porifera					
Iotrochota protea	1.0	0.1			
Algae					
Codium edule	0.1			0.1	
Desmia hornemannii	0.1				0.1
Dictyopteris australis			0.1		
Tolypiocladia glomerulata			0.5		
Halimeda discoidea		0.5			
Sand	5	88.6	30	3	4
Rubble					2
Hard Substratum	91.3	10	69.4	96.9	93.9

B. 40-Point Analysis

Species	Percent of Total
Sand	30
Hard Substratum	70

TABLE 1. Continued

C. **Invertebrate Census (20 x 4 m)**

Species	**Number**
Phyllum Mollusca	
Conus sponsalis	1
Phylum Echinodermata	
Echinometra mathaei	31
Tripnuestes gratilla	6

D. **Fish Census Summary (20 x 4 m)**

6 species
18 individuals

Diversity (H')= 1.44

Besides the organisms listed in Table 1, the qualitative reconnaissance noted the soft coral (*Palythoa tuberculosa*), the large polychaete (*Loimia medusa*), and the leopard cone (*Conus leopardus*) in the vicinity of Transect 1. Fishes encountered in the area outside of the 20 x 4 m quantitative survey site include the moana (*Parupeneus multifasciatus*), sharpback puffer (*Canthigaster ambioensis*), hinalea (*Thalassoma duperryi*), puhi paka (*Gymnothorax flavimarginatus*), humuhumu (*Sufflamen bursa* and *Rhinecanthus aculeatus*), butterflyfish (*Chaetodon kleini*), hawkfish (*Paracirrhites forsteri*) and a damselfish (*Chromis vanderbilti*).

STATION 2

Station 2 was located approximately 60 meters (200 feet) east of Station 1, in water 7 to 8 meters (25 feet) deep, essentially just beyond the area proposed to be dredged for the East Channel Alignment. This station, like the preceding one, was about 800 m (2600 feet) offshore but situated near the center line of the proposed channel. The area was selected as being representative of the shallow ridge and groove bottom with moderate coral cover seen near Station 1.

The substratum at this site is a relatively flat limestone crossed by low ridges, the latter harboring the coral *Porites lobata* (Figure 6). Coral heads attain diameters of up to 1.25 m (4 feet), and are spaced from 0.5 to 5 m (1.5 to 16 feet) apart. *Porites* covers perhaps 30 to 40 percent of the ridge surfaces and bottom coverage overall approaches 20 percent. Table 2 presents the data from a quantitative transect at Station 2.

TABLE 2.

Summary of the benthic survey conducted at Station 2 on the proposed East Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth is approximately 7 m; mean coral coverage is 14.7 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata	40	2	2	19	8
Porites compressa				0.5	
Porites evermanni				2	
Pocillopora meandrina		0.1		0.1	
Hard Substratum	60	97.9	98	78.4	92

40-Point Analysis

Species	Percent of Total
Corals	
Porites lobata	17.5
Hard Substratum	82.5

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum Echinodermata	
Echinometra mathaei	64
Tripnuestes gratilla	1
Echinostrephus aciculatum	4

D. Fish Census Summary (20 x 4 m)

21 species
57 individuals

Diversity (H')= 2.50

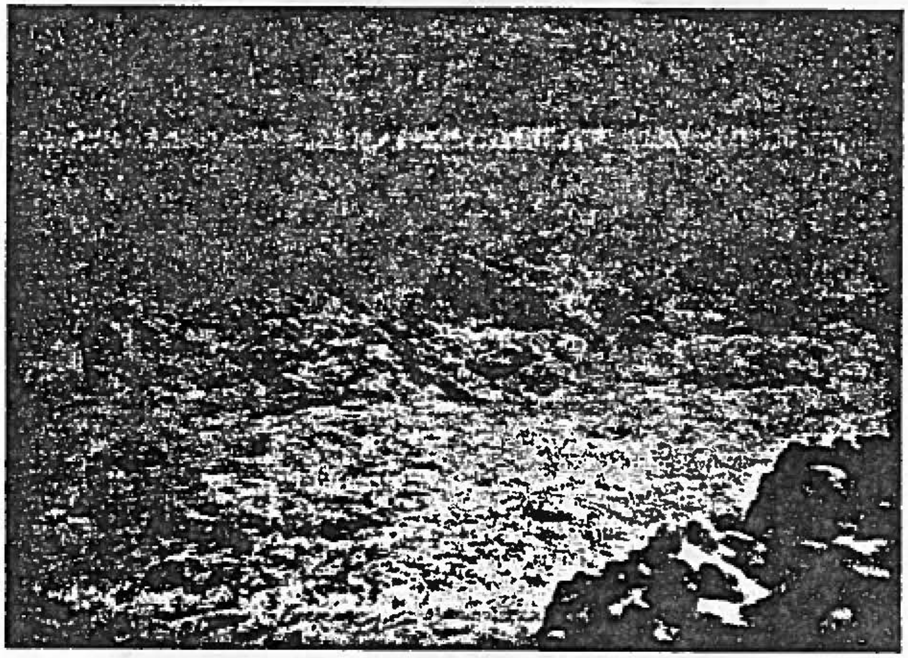


Figure 6. Station 2 showing heads of *Porites lobata* in foreground and background.

Coral species present in this area include *Porites lobata*, *P. compressa*, *P. evermanni* and *Pocillopora meandrina*. Invertebrates encountered in the vicinity of Station 2 include a polychaete (*Spirobranchus* sp.), a swimming crab (*Charybdis orientalis*), and a soft coral (*Palythoa tuberculosa*).

The greatest number of fish species (21 species) recorded at any station were censused at this locality (Appendix 1). Besides the fishes given in Appendix 1, species seen in the area around Station 2 include the puffer (*Arothron hispidus*), piliko`a (*Cirrhitops fasciatus*), `ala`ihi (*Adioryx lacteoguttatus*) and the humuhumu (*Rhinecanthus aculeatus*).

STATION 3

Station 3 was established about 640 m (2100 feet) offshore and on the center line of the proposed East Channel Alignment, immediately west of a large submarine sand patch (Figure 1). Water depth is around 2 meters (between 6 and 8 feet). The bottom is an irregular limestone surface, with vertical relief on the order of 0.5 to 1 meter (1 to 3 feet)(Figure 7). Meandering grooves and small channels, 1 to 3 meters (3 to 10 feet) across and containing sand, rubble, and worn and rounded boulders (these on the order of 10 to 50 cm or 4 to 20 inches across), occur throughout the area. These complex depressions are spaced from 5 to 10 meters (15 to 35 feet) apart.

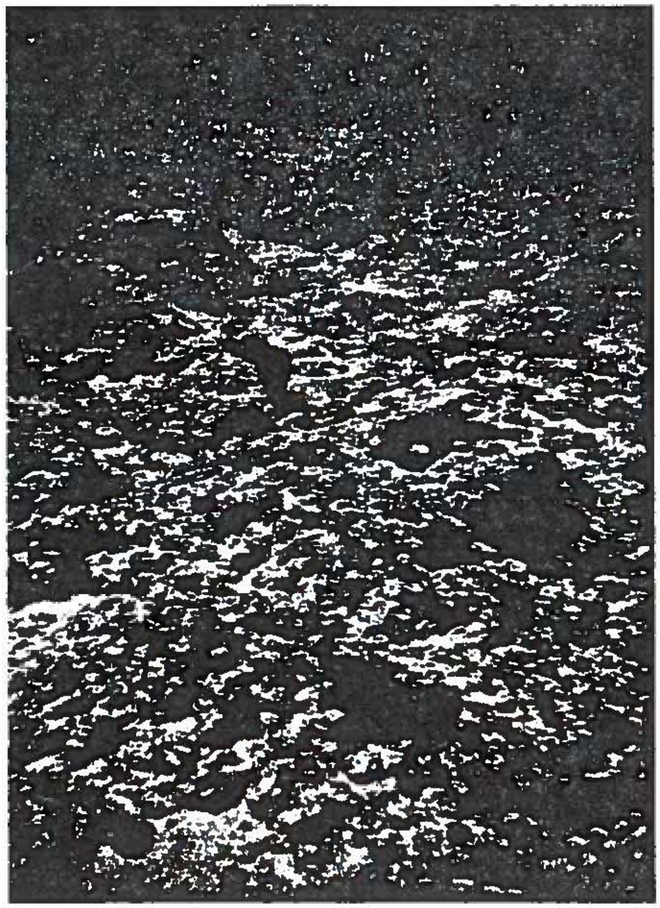


Figure 7. Rubble-covered limestone bottom at Station 3.

The sand patch is a distinct feature lying directly shoreward of a shoal area marking the outer edge of the reef. Seaward of this shoal (between Station 3 and Stations 1 and 2) the bottom drops away rapidly (the upper reef face) and is mostly limestone cut by grooves. In some areas, the grooves have sand bottoms.

Very little algae occurs on the bottom around Station 3 -- that which is present consists of scattered growths of *Asparagopsis taxiformis*, *Codium edule*, and *C. arabicum*. Coral cover is also sparse, consisting of scattered heads of *Pocillopora meandrina* and *Porites lobata*, both generally on the order of 20 to 40 cm (8 to 16 inches) across. Coral cover is less than 2% of the bottom. Many damaged and dead heads of *Poc. meandrina* are present. Table 3 presents the results of the quantitative transect at Station 3. A total of six invertebrate species were enumerated in the transect survey. Invertebrate species met with in the area removed from the quantitative survey include the octopus (*Octopus cyanea*), sea urchin (*Echinostrephus aciculatum*) and the cone shell (*Conus distans*). Wana urchins (*Echinothrix diadema*) are common in this area (see Figure 8).

Eight species of fish were censused in the transect survey (Appendix 1). In the vicinity of Station 3 were seen the fishes hinalea `akilolo (Coris gaimard), manini (Acanthurus triostegus sandvicensis), `awela (Thalassoma fuscum), ma`i`i`i (Acanthurus nigrofuscus), moano (Parupeneus multifasciatus), umaumalei (Naso literatus), a wrasse (Labroides phthirophagus), piliko`a (Paracirrhites arcatus) and a butterflyfish (Chaetodon quadrimaculatus).

TABLE 3.

Summary of the benthic survey conducted at Station 3 on the proposed East Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth is approximately 2 m; mean coral coverage is 1.1 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata	0.5	0.3		2	1
Porites evermanni	0.5				
Pocillopora meandrina	1				
Algae					
Codium edule	1	0.1			
Codium arabicum		0.1			
Halimeda discoidea		0.1	0.1		
Sand				9	6
Rubble	15	6	40	34	65
Hard Substratum	82	93.3	59.9	55	28

B. 40-Point Analysis

Species	Percent of Total
Corals	
Porites lobata	2.5
Sand	7.5
Rubble	25
Hard Substratum	65

TABLE 3. Continued.

C. **Invertebrate Census (20 x 4 m)**

Species	Number
Phylum mollusca	
Drupa morum	1
Conus lividus	1
Phylum Echinodermata	
Echinometra mathaei	5
Echinothrix diadema	18
Tripnuestes gratilla	1
Holothuria atra	2

D. **Fish Census Summary (20 x 4 m)**

8 species
48 individuals

Diversity (H')= 1.58

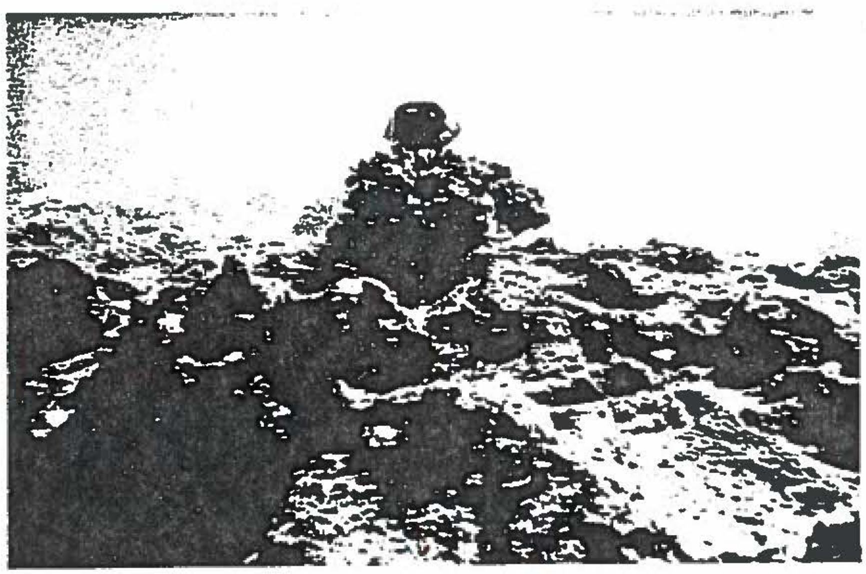


Figure 8. Area of limestone bottom and moderate relief at Station 3. Seen are the coral, *Poc. meandrina*, wana or *Echinothrix diadema*, and the butterflyfish, *Chaetodon quadrimaculatus*.

STATION 4

Station 4 was established in the center of the proposed East Channel Alignment about 240 m (800 feet) from shore in 2.5 to 3 meters (8 to 10 feet) of water. The bottom here is generally similar to that seen at Station 3, only slightly deeper. Bottom relief is also somewhat less. The substratum is scoured limetone with scattered depressions, shallow grooves and meandering channels and dips that are from 0.5 to 1.5 meter (1 to 4 feet) in diameter and up to 50 cm (18 inches) deep. These depressions are spaced from 0.5 to 0.75 meter (1.5 to 2 feet) apart. A thin layer of silty-sand covers most surfaces (see Figures 9, 10, and 11).

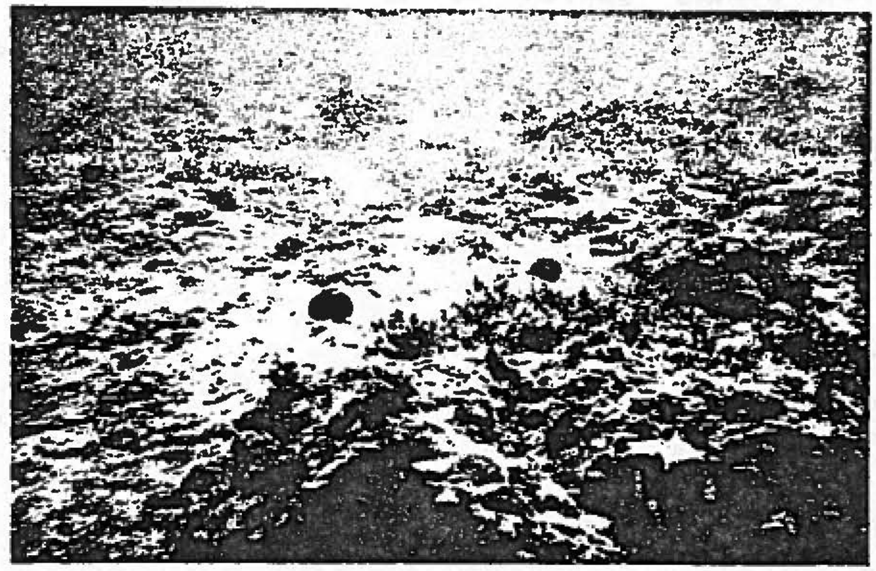


Figure 9. Irregular bottom of limestone at Station 4. Note small, encrusting Porites lobata in foreground.

Algae are somewhat more abundant than further offshore, dominated by Asparagopsis taxiformis and Codium edule. Coral cover is low, between 1 and 3% of the bottom, consisting almost entirely of Porites lobata Pocillopora meandrina, and P. molokensis heads. Other corals seen in the vicinity of this station are Porites compressa and the soft coral, Palythoa tuberculosa. Other invertebrates noted in the vicinity of this station include cone shells (Conus leopardus and Conus distans) and a mantis shrimp (Gonodactylus sp.). The small mussel, Brachidontes crebristriatus, is a common component of the benthos at this station. It occurs in densities up to approximately 200 individuals per 100 cm^2 of substratum. In localized areas, the urchin Tripneustes gratilla is very abundant on the bottom. In other areas, holothurians (Holothuria atra) are moderately common. Sponges (Iotrochota protea) and small anemones (Aiptasia pulchella) are common, as they are at Station 1 off the front of the reef.

TABLE 4.

Summary of the benthic survey conducted at Station 4 on the proposed East Channel Alignment for the Ewa Marina, \`Ewa, O\`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth is approximately 2.5 m; mean coral coverage is 0.9 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	**Quadrat Number** 1	2	3	4	5
Corals					
Porites lobata			0.5	1	
Porites molokensi			3		
Soft corals					
Zoanthus sp.			0.5		
Algae					
Jania sp.				0.1	
Corallina sp.			0.1	0.1	
Amphiroa fragilissima			0.1		
Codium edule	0.1	0.2		0.3	1
Halimeda opuntia	0.5		1		0.1
Asparagopsis taxiformis	0.5				
Mollusks					
Brachidontes crebristriatus	70				
Rubble		2			
Hard Substratum	28.9	97.8	94.8	98.5	98.8

B. 40-Point Analysis

Species	**Percent of Total**
Corals	
Porites lobata	2.5
Porifera	
Iotrochota protea	2.5
Hard Substratum	65

TABLE 4. Continued.

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum mollusca	
Conus miliaris	1
Phylum Echinodermata	
Echinometra mathaei	46
Tripnuestes gratilla	16
Holothuria atra	7

D. Fish Census Summary (20 x 4 m)

4 species
18 individuals

Diversity (H')= 0.88

Table 4 presents the results of the quantitative survey conducted at this station. Four species of diurnally exposed macroinvertebrates were censused. The most common species in the transect is the sea urchin, Echinometra mathaei. Only four species of fishes were censused at Station 4 (Appendix 1). Besides these species, a puffer (Arothron hispidus), puhi (Gymnothorax undulatus), sharpback puffer (Canthigaster coronata) and `awela (Thalassoma fuscum) were seen nearby.

Figure 10. Area of Asparagopsis taxiformis growth at Station 4.

Figure 11. Closeup of the urchin, Tripneustes gratilla, on undulating bottom at Station 4.

STATION 5

Station 5 was located about 60 m (200 feet) offshore of the emergent limestone bench at Keku Point, in about 2 m (5 to 6 feet) of water. This station was situated in the approximate center of the proposed East Channel Alignment. The substratum at this station is limestone that is heavily bisected by a series of small spurs, grooves and depressions. These channels and pockets have a general orientation perpendicular to shore; their dimensions range from 1 to 4 meters (3 to 12 feet) in width, 1 to 5 meters (3 to 16 feet) in length, and they attain a maximum depth of about 75 cm (30 inches). These features are spaced from 0.5 to 3 meters (1.5 to 10 feet) apart. A veneer of sand covers much of the limestone bottom.

In contrast to the other stations surveyed, this complex substratum is dominated by macroalgae. Common species include Hypnea multiformis, H. cervicornis, Acanthophora spicifera, Codium edule, Amphiroa fragilissima, Laurencia nidifica, Sargassum obtusifolium, and encrusting calcareous forms. Eighteen species were recorded in the quadrat (transect) survey (see Table 5). An algal turf, dominated by Jania sp. and Corallina sp., appears to hold sand to the bottom. In some areas, the mussel, Brachidontes crebristriatus, is abundant (as at Station 4). The holothurian, Holothuria atra is common to abundant. There are no corals present in the area; algae and sand cover most of the hard substratum. Three invertebrate species were censused and four others were seen nearby including ula (lobster; Panulirus penicillatus), wana (sea urchin; Echinothrix diadema), sea cucumber (Actinopyge mauritiana) and cone shell (Conus lividus).

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TABLE 5.

Summary of the benthic survey conducted at Station 5 on the proposed East Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B, and counts of invertebrates in Part C. A summary of the fish census is given in Part D. Water depth is approximately 2.1 m; mean coral coverage is 0 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Soft corals					
Zoanthus sp.	1				
Algae					
Asparagopsis taxiformis			1		
Codium edule	5	6	6	6	5
Amphiroa fragilissima	4	8	4	2	1
Corallina sp.	2	2	4	8	
Enteromorpha sp.	1				
Laurencia obtusa	0.5				
Dictyota sandvicensis	3	1		1	
Dictyota friabilis	5	4	1		
Dotyella hawaiiensis	0.5		1		
Dictypteris australis	6	4			
Acanthophora spicifera		2		3	2
Galaxaura filamentosa		1			
Peyssonellia rubra	0.5	0.5			
Desmia hornemannii		2	3		
Codium reediae			2		
Ulva fasciata			1		5
Halimeda opuntia	0.5		1		0.1
Spyridia filamentosa	8				
Hard Substratum	63.5	69.5	76	80	87

B. 40-Point Analysis

Species	Percent of Total
Algae	80
Hard Substratum	20

==

TABLE 5. Continued.

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum Arthropoda	
Calcinus sp.	1
Phylum Echinodermata	
Tripnuestes gratilla	2
Holothuria atra	26

D. Fish Census Summary (20 x 4 m)

4 species
28 individuals

Diversity (H')= 1.06

Only four species of fishes were enumerated in the census at Station 5 (Appendix 1). Three other species were seen in the vicinity including the manini (*Acanthurus triosfegus sandvicensis*), \`awela (*Thalassoma fuscum*) and the umaumalei (*Naso literatus*). Table 5 presents the results of the quantitative survey conducted at this Station 5.

Figure 12. Limestone bottom at Station 5 dominated by macroalgae.

STATION DESCRIPTIONS, WEST CHANNEL ALIGNMENT

STATION 6

Station 6 was established 1100 meters (3600 feet) from shore off the front of the proposed West Channel Alignment at a depth between 7 and 8 meters (22-26 feet). The bottom is a mixture of sand and hard substrata, the latter mostly as low, well spaced ridges running perpendicular to the reef margin (Figure 13). Small depressions, 1 to 3 m (3 to 6 feet) across and up to 30 cm (1 foot) deep are spaced 2 to 10 m (6 to 10 feet) apart over the bottom. These pockets are filled with rubble and sand. Fairly large expanses of sand bottom (as a veneer over limestone) are present in this area.

Live coral, mostly *Porites lobata*, covers up to 50% of the low ridge features (Figure 14). Colonies attain a maximum diameter of 1.5 meter (5 feet) -- mean colony size is approximately 75 cm (2.5 feet). Overall or average coral coverage at this station is less than 10 percent of the bottom. The intervening areas of sand veneer over limestone harbor sponges (mostly *Iotrochota protea*) and small anemones (*Aiptasia pulchella*). Table 6 presents the results of the quantitative transect survey at Station 6.

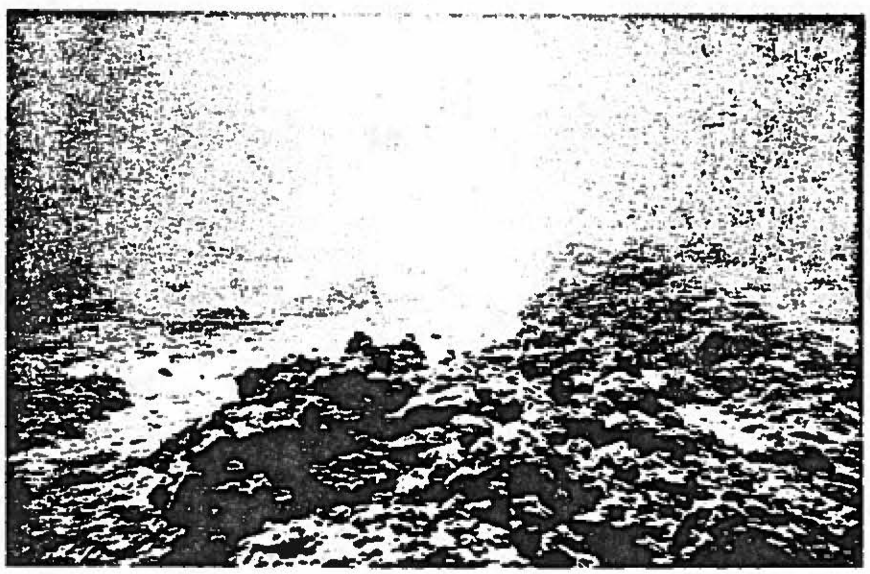

Figure 13. Bottom at Station 6 with transect line crossing low ridges of *Porites lobata* oriented perpendicular to reef front.

Only one coral species (*Porites lobata*) was encountered in the quadrat survey; other species seen in the vicinity include *Montipora patula*, *Pavona varians*, *Pocillopora meandrina*, *Porites evermanni* and the soft coral, *Palythoa tuberculosa*. In addition to the three invertebrate species (all sea cucumbers) censused in the 20 x 4 cm area, a leopard cone (*Conus leopardus*) was recorded outside of this area.

TABLE 6.

Summary of the benthic survey conducted at Station 6 on the proposed West Channel Alignment for the Ewa Marina, \`Ewa, O\`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A summary of the fish census is given in Part D. Water depth is approximately 7.6 m; mean coral coverage is 4.4 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata	6	5	9		2
Porifera					
Iotrochota protea		1	1	1	
Chordata					
Didenum candidum			1		
Sand		7			
Hard Substratum	94	87	89	99	97

B. 40-Point Analysis

Species	Percent of Total
Corals	
Porites lobata	15
Sand	10
Hard Substratum	75

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum Echinodermata	
Echinometra mathaei	43
Tripnuestes gratilla	3
Echinostrephus aciculatum	7

TABLE 6. Continued.

D. **Fish Census Summary (20 x 4 m)**

18 species
69 individuals

Diversity (H')= 2.12

Eighteen species of fish were censused (Appendix 1) on the transect. In the vicinity were seen a small school of `opelu (Decapturus pinnulatus), butterflyfishes (Chaetodon ornatissiums, C. miliaris, C. kleini, C. lunula, C. multicinctus and C. quadramaculatus), sharpback puffer (Canthigaster coronata), kihikihi (Zancleus cornutus), damselfish (Dascyllus albisella), manini (Acanthurus triosfegus sandvicensis) and the `awela (Thalassoma fuscum).

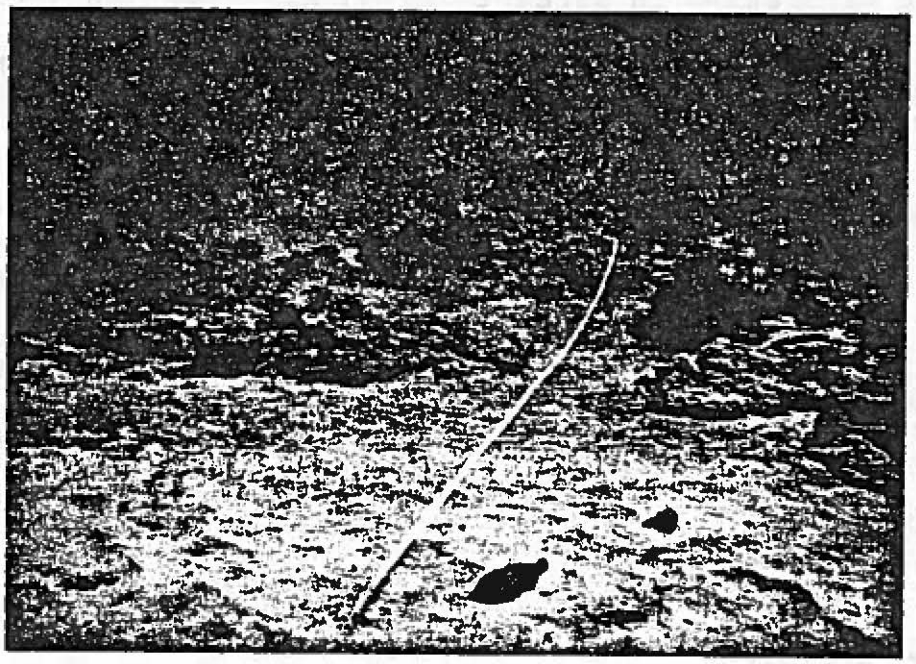

Figure 14. The bottom and transect line off the reef front at Station 6. Note the coral, Porites lobata, in the background and the ubiquitous filefish, Pervagor spilosoma.

STATION 7

Station 7 was established at a depth of around 4 meters (12-15 feet) about 670 meters (2200 feet) offshore near the center line of the West Channel Alignment (Figure 1). The bottom is limestone with relatively little silty-sand veneer . Irregular mounds of live and dead coral (mostly *P. lobata*) are scattered over a slightly indulating surface pocked by scattered and complex reticulations and depressions (see Figures 15 and 16). These features range in size from 0.5 to 5 m (1 to 15 feet) across, and most are no more than 50 cm (less 2 feet) deep and spaced from 0.5 to 2 m (1 to 6 feet) apart. Superimposed on this topography are larger circular depressions 4 to 5 m (12 to 15 feet) across and about a meter (3 feet) in depth (Figure 17). These large circular depressions are about 20 to 30 m (60 to 100 feet) apart. The uniformity in size and the distance offshore suggest that this area may have been part of a World War II target range (the zone of impact). Indeed, two objects were seen that appeared to be ordinance (from approximately 220 mm shells) to the east of the transect location.

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TABLE 7.

Summary of the benthic survey conducted at Station 7 on the proposed West Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A summary of the fish census is given in Part D. Water depth is approximately 4.3 m; mean coral coverage is 11.7 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number				
	1	2	3	4	5
Corals					
Porites lobata	3	18	5	15	7
Porites evermanni	4		1		
Porites compressa			2	0.5	2
Pocillopora meandrina	1				
Soft corals					
Palythoa tuberculosa		0.5			
Algae					
Codium edule	1				
Rubble				15	25
Hard Substratum	91	81.5	92	69.5	66

==

TABLE 7. Continued.

B. 40-Point Analysis

Species	Percent of Total
Corals	
Porites lobata	22.5
Hard Substratum	77.5

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum Mollusca	
Conus lividus	1
Phylum Echinodermata	
Echinometra mathaei	79
Echinothrix diadema	1
Tripnuestes gratilla	48
Holothuria atra	1

D. Fish Census Summary (20 x 4 m)

6 species
26 individuals

Diversity (H')= 1.21

The sea urchins, *Tripneustes gratilla* and *Echinometra mathaei*, are very abundant in this area. *T. gratilla* dot the surface at a density estimated during reconnaissance of the area to be 4-5 per m^2. *Echinometra mathaei* are slightly less abundant (2-3 per m^2) overall, but are locally congregated, occuring in grooves of various lengths bored by the urchins in the hard substratum. Wana urchins (*Echinothrix*) are present, usually associated with holes and overhangs in the scattered coral mounds. Octopus (*Octopus cyanea*) is common in the vicinity of the station, as is a black encrusting sponge (*Iotrochota protea*). Also present at this station is the coralline alga, *Porolithon gardineri*, forming small (15 cm or 6 inch diameter) heads that superficially resemble corals.

The results of the quantitiative survey conducted at Station 7 are given in Table 7. Four coral species provide a mean coverage close to 12 percent; one additional species (*Montipora patula*) was seen nearby as was the soft coral, *Palythoa tubercu-*

losa. Sea urchins (*Tripneustes gratilla* and *Echinometra mathaei*) are the most common invertebrates censused in the 20 x 4 m survey area.

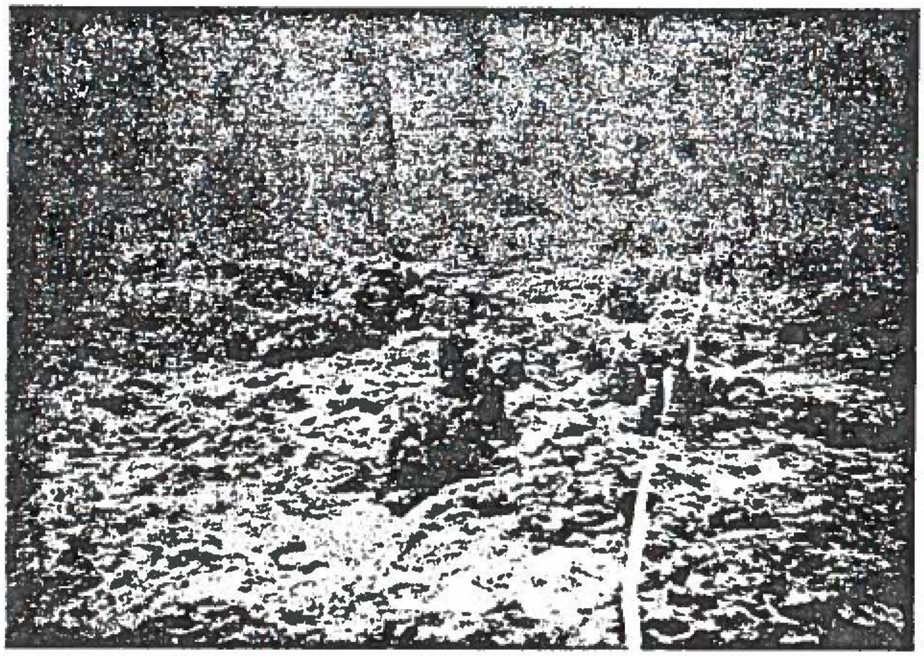

Figure 15. Transect line on the bottom at Station 7. A few small coral heads are evident in the photograph.

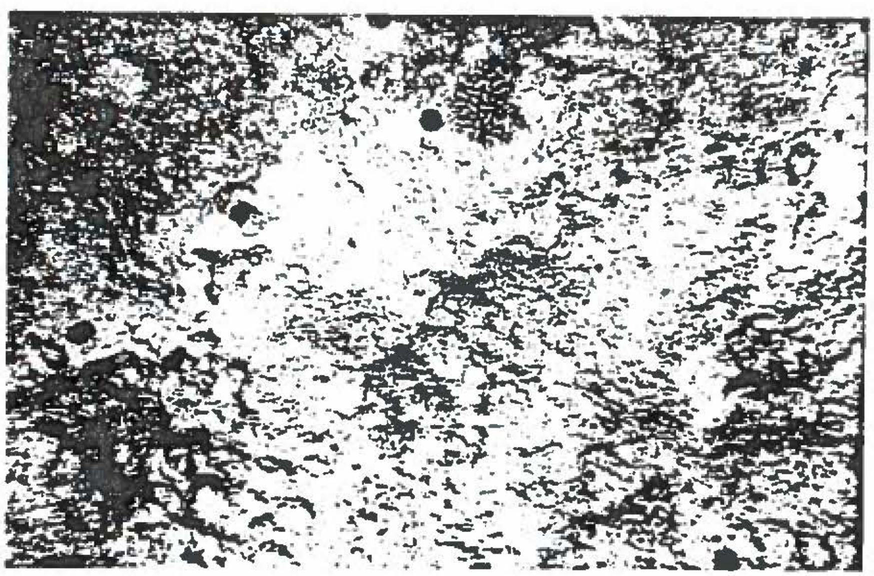

Figure 16. Vertical view of the bottom at Station 7. Most evident are the coral, *Pocillopora meandrina*, the urchin, *Tripneustes gratilla*, and meandering grooves cut by the boring urchin, *Echinometra mathaei*.

Figure 17. Example of a 5-meter (16-foot) wide, 1-meter (3-foot) deep crater probably formed by the impact of artillery on the reef at Station 7.

Six fish species were censused at Station 7. The humuhumu (*Rhinecanthus aculeatus* and *Sufflamen frenatus*), sharpback puffers (*Canthigaster jactator* and *C. amboinensis*), moa (*Ostracion meleagris*) and hinalea `akilolo (*Coris gaimardi*) were seen in the surrounding area.

STATION 8

Station 8 was located in water 3 meters (10-12 feet) deep over a bottom of mixed reef limestone and sand overlain with rubble and scattered boulders (Figure 18). Distance offshore was about 420 meters (1400 feet) along the proposed West Channel Alignment. Sand and rubble cover 60 to 75 percent of the substratum. Extensive areas of all sand bottom occur on this part of the reef. Areas of limestone are undercut, providing shelter for larger fishes.

Algae are relatively more abundant here than at the offshore stations; prominant species are *Codium edule*, *Amphiroa fragilissima*, *Corallina* sp., *Padina japonica*, *Hypnea cervicornis*, *Halimeda discoidea*, and *Dictyota sandvicensis*.

Corals are rare, occupying about 0.1 percent of the substratum. One coral species was recorded (*Porites lobata*) in the quantitative survey. Outside of the transect the soft coral (*Palythoa tuberculosa*) and one small *Pocillopora meandrina* colony were noted. Macroinvertebrates are not particularly common (only four species in the census - see Table 8). In addition, the octopus (*Octopus cyanea*), wana (*Echinothrix diadema*), mussels (*Brachidontes crebristriatus* in densities of approximately 70 to 100 cm^2), and an encrusting blue sponge are present in the area.

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TABLE 8

Summary of the benthic survey conducted at Station 8 on the proposed West Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A summary of the fish census is given in Part D. Water depth is approximately 3 m; mean coral coverage is 0.1 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata				0.5	
Algae					
Codium edule	0.5				2
Corallina sp.	7	1		5	2
Spyridia filamentosa	0.5				
Amphiroa fragilissima	1			1	
Halimeda discoidea		1		0.5	
Gracilaria bursapastoris				0.5	
Galaxaura fastigiata					6
Sand	61	92	60	30	25
Rubble	30				65
Hard Substratum		4	40	62.5	

B. 40-Point Analysis

Species	Percent of Total
Sand	42.5
Rubble	22.5
Hard Substratum	35

==

TABLE 8. Continued.

C. **Invertebrate Census (20 x 4 m)**

Species	Number
Phylum Mollusca	
<u>Conus lividus</u>	1
Phylum Arthropoda	
<u>Calcinus</u> sp.	1
Phylum Echinodermata	
<u>Tripnuestes gratilla</u>	1
<u>Holothuria atra</u>	2

D. **Fish Census Summary (20 x 4 m)**

2 species
3 individuals

Diversity (H')= 0.64

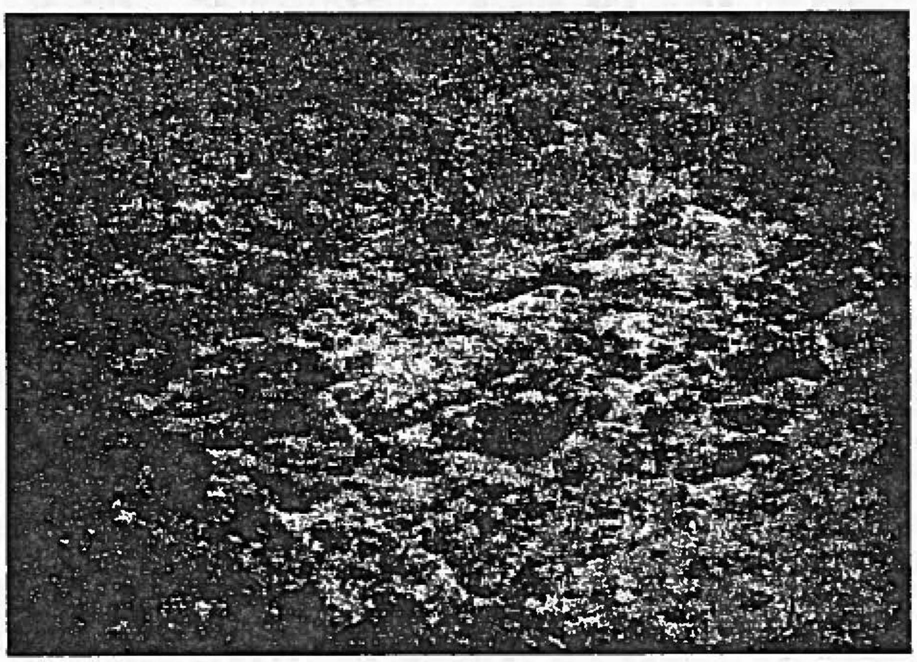

Figure 18. Bottom at Station 8. Note the dominance of sand and abundance of macroalgae on boulders.

Only two species of fish were recorded in the census (see Appendix 1). Outside of the transect area were seen the puhi paka (Gymnothorax flavimarginatus), puffer (Arothron hispidus), `omaka (Stethojulis balteata), hinalea (Thalassoma duperryi), palani (Acanthurus dussumieri) and wrasse (Coris venusta).

STATION 9

Station 9 was conducted along the seaward edge of a submerged limestone block (old beachrock formation) located about 120 meters (400 feet) off and roughy parallel to the shoreline (Figure 19). Depth of water over the limestone block is about one meter (2 to 3 feet). The upper surface of the submerged beachrock slopes seaward at a 30 degree angle until it meets a limestone substratum covered with sand and rubble at a water depth of 2 meters (6 feet). The massive formation is fractured and undercut, providing cover for fishes. Depth at the transect was 2 to 2.5 meters (6 to 8 feet).

Corals are very sparse in this shallow, high energy environment. One species (Porites lobata) was encountered in the quadrat survey. Elsewhere Porites evermanni, Pavona varians, and Pocillopora meandrina are seen but nowhere does the coral cover exceed 0.5 percent. Table 9 presents the results of the quantitative survey carried out at Station 9.

Algae are common on the limestone bottom and they have a coverage of about 5 percent. Four invertebrate species including the octopus (Octopus cyanea) were encountered in the census. In the surrounding area the mussel (Brachidontes crebristriatus) and a large Samoan crab (Scylla serrata) were seen. This crab normally inhabits brackish or estuarine waters and its occurrence in a marine habitat is unusual.

Thirteen species of fishes were censused on this transect (Appendix 1) including commercially important species such as the moano (Parupeneus multifasciatus, up to 1.5 kg) and kumu (Parupeneus porphyreus). Away from the transect other commercially important fishes seen include `aweoweo (Priacanthus cruentatus), malu (Parupeneus pleurostigma) and pualu (Acanthurus xanthopterus). Other fishes seen in the vicinity include the hinalea (Thalassoma ballieui), ma`i`i`i (Acanthurus nigrofuscus), `awela (Thalassoma fuscum), `ala`ihi (Adioryx lacteoguttatus), kihikihi (Zancleus cornutus) and damsel fishes (Chromis ovalis, Stegastes fasciolatus, and Abudefduf sindonis).

The massive beachrock "block" is a geologically interesting feature providing somewhat unique habitat for a variety of organisms within relatively easy reach of the shore. This area would appear to be a popular destination for skin-divers, although at the present time this section of the coastline is not heavily used by divers, possibly because of generally poor water clarity.

TABLE 9

Summary of the benthic survey conducted at Station 9 on the proposed West Channel Alignment for the Ewa Marina, `Ewa, O`ahu. Results of the 5 m^2 quadrat sampling of the benthic community present (expressed in percent cover) are given in Part A; a 40-point analysis is presented in Part B; and counts of invertebrates in Part C. A summary of the fish census is given in Part D. Water depth is approximately 2.4 m; mean coral coverage is 0.3 percent (quadrat method).

A. Quadrat Survey (percent cover)

Species	Quadrat Number 1	2	3	4	5
Corals					
Porites lobata			1.5		
Porifera					
Red sponge sp.		0.5			1
blue encrusting sponge			1		
Algae					
Codium edule	8	12	3		
Corallina sp.	0.5			1	1
Amphiroa fragilissima			0.5		
Halimeda discoidea					0.5
Dictyota acutiloba					0.1
Sand					4
Rubble		15	2		
Hard Substratum	91.5	72.5	92	99	93.4

B. 40-Point Analysis

Species	Percent of Total
Sand	5
Rubble	10
Hard Substratum	85

TABLE 9. Continued.

C. Invertebrate Census (20 x 4 m)

Species	Number
Phylum Molluska	
Octopus cyanea	1
Conus lividus	1
Phylum Echinodermata	
Holothuria atra	1
Actinopyge mauritiana	1

D. Fish Census Summary (20 x 4 m)

13 species
70 individuals

Diversity (H')= 1.81

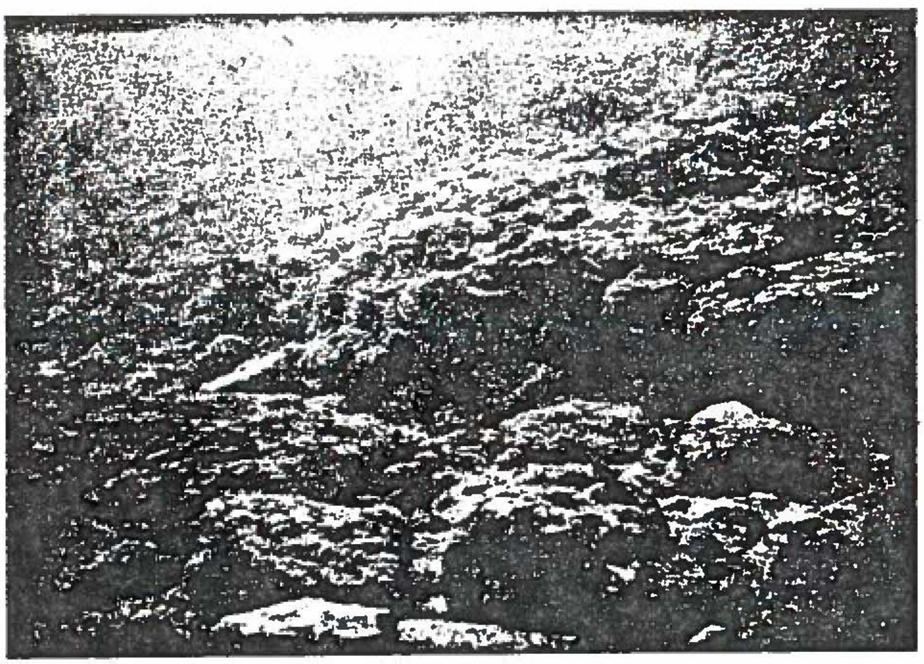

Figure 19. Seaward face of the sloping beachrock "block" at Station 9. Note the undercut edge providing habitat for fishes and cryptic invertebrates.

DISCUSSION

This discussion section is intended to supplement the information and impact assessment presented in the EIS for Increment II of the proposed Ewa Marina Community (Dames & Moore, 1985). Figure 20 illustrates the spatial relationships between the present survey sites and earlier surveys conducted on the reef off the Ewa Marina project site. The results of the surveys suggest that there are some common features among the stations. The dominant substratum component is solid limestone overlain in many places by rubble and/or sand. The paucity of corals and prostrate growth forms of most corals encountered in this area suggest that high energy conditions must impinge on extant benthic communities with some frequency. Storm surf is probably a major influence on these communities. The diversity and abundance of organisms present at any of the stations was not particularly high; the depauperate nature of the biota is probably a reflection of the shallow water, unstable silty-sand, and frequent high energy conditions. The anticipated impacts of channel construction are considered below within the broad categories of physical environment (substratum), algae, corals, other invertebrates, and fishes.

Substratum. The substratum at most of the study sites is limestone, overlain by a veneer of sand and/or rubble. Areas of consolidated limestone with minimal fine sediment accumulation are limited to the reef margin and relatively shallow bottom directly shoreward of the reef margin (e.g., Stations 3 and 7). The scoured appearance of much of the bottom is an indication of frequent high wave energy conditions. However, silty-sand lightly coats or covers the bottom in most areas. Some of this thinly-spread reservoir of fine material (a survey by Noda, 1985 indicated that even the large sand patches have sediment thicknesses of only a few feet) is readily stirred into suspension by each passing wave swell and contributes to the generally turbid water conditions which typify the shallow marine environment off `Ewa.

Approximately 110,000 square meters (129,000 square yards) of reef flat would be dredged to create the entrance channel for the Ewa Marina (Dames & Moore, 1985). The dredging of this channel will result in a swath of deeper bottom across the reef flat, creating a mostly sand-bottom feature with relatively steep, high relief margins. A portion of the reef flat near the middle of the proposed channel is deeper than the -15 feet project depth in this section. This area of the reef is presently characterized by an accumulation of soft sedimentary material and low limestone outcrops, and might typify what the bottom along most of the channel alignment would be after completion of the dredging project.

The channel margins will probably be of the nature of a sloping limestone face varying between one and over three meters

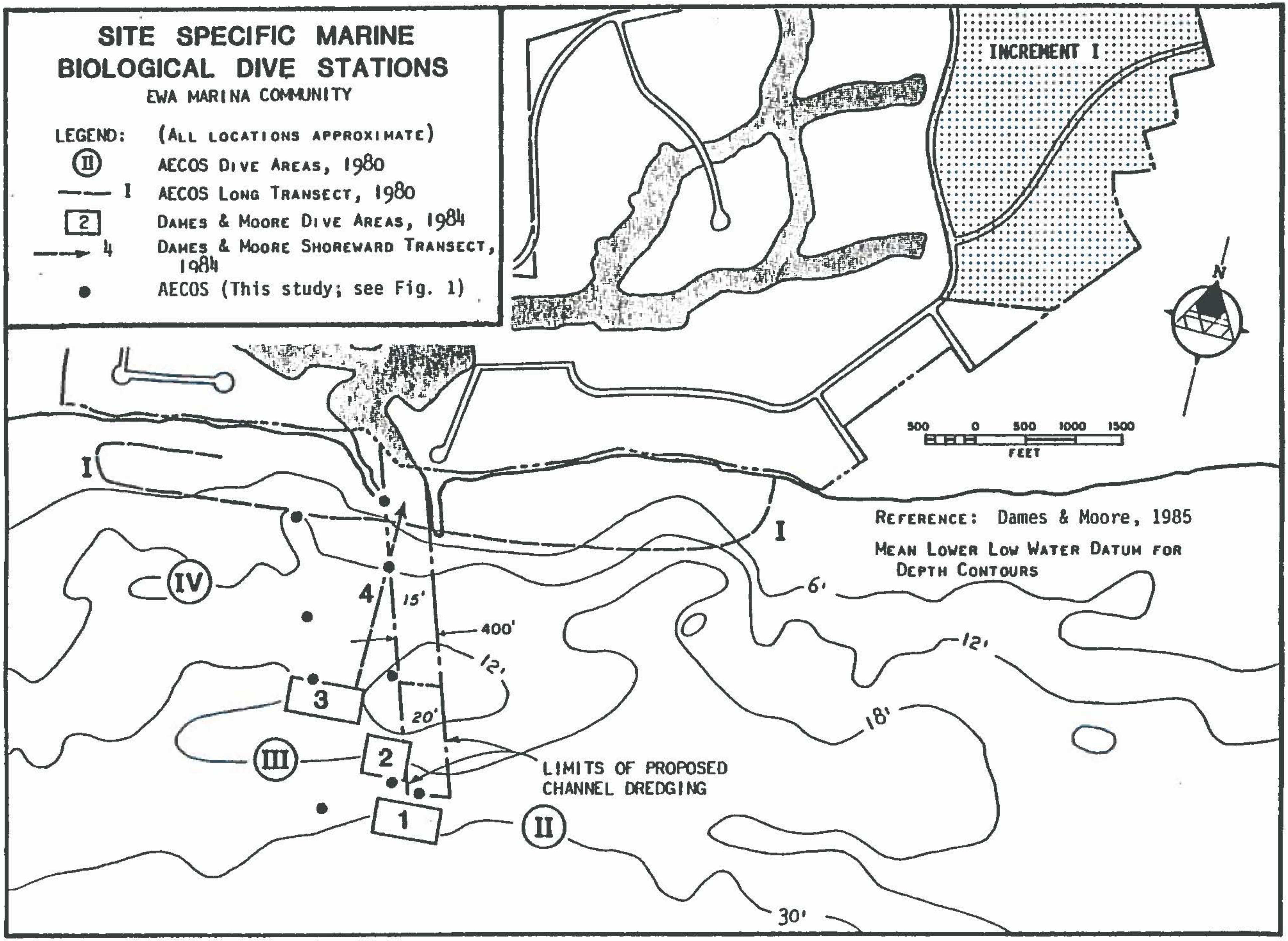

Figure 20. Marine biological dive stations off the Ewa Marina Community project site.

(3 to 10 feet) high. Breakwaters proposed for both sides of the entrance channel (Dames & Moore, 1985) would further alter the existing nearshore limestone bottom and create additional high relief submerged bottom and complex intertidal surfaces. The creation of relatively high relief, limestone bottom (e.g., along the margins of the entrance channel) can be expected to enhance certain fish and invertebrate populations by providing localized cover. This effect could more than offset the anticipated loss of available cover (which is presently low in most areas) resulting from dredging of certain limestone bottom areas.

Impacts on the physical environment from channel construction would include increases in water turbidity, redistribution of fine sedimentary materials disturbed by dredging, and perhaps blast effects (from the use of high explosives to remove hard bottom) and bottom damage caused by anchors and anchor lines. The construction of an entrance channel for the Barbers Point Deep Draft Harbor demonstrated that a localized turbidity plume is generated by dredging activities on a reef flat such as that off `Ewa (see AECOS, 1982; AECOS, 1986). Turbidity values in such a plume might range between 10 and 20 NTUs.

The impact of the Barbers Point harbor dredging project on the benthic environment was assessed by AECOS (1985). Significant impacts appear to have occurred over a relatively small area surrounding the harbor entrance channel, although difficulty in distinguishing impacts due to construction from impacts due to major storms was cited as possibly contributing to the report's conclusions. Local currents transporting and dispersing suspended sediments out of the area was cited as a mechanism which reduced the impact of dredging on the reef environment. Sediment accumulation on the bottom presumably traceable to channel dredging (that is, seen during channel construction) contrasted with observations made prior to construction (in 1979, see Bienfang and Brock, 1980) and after construction (post-construction benthic surveys, see AECOS, 1985). The 1985 report stated "there were no signs of excessive sediment accumulation (particularly very fine sediments) in the areas surveyed", which extended over 0.5 km (0.3 mile) north and south of the new channel and from near the shore to an offshore depth of 14 meters (45 feet).

Blast impacts are difficult to predict because of the complex relationships between size of charge, water depth, depth of charge (in substratum), and distance from blast. Localized damage to fishes and invertebrates will occur from the shock wave generated in the water column by the blast, although proper precautions (i.e., limitations on the size of the charge, separation by milliseconds of multiple blasts, etc.) can substantially reduce the area of potentially significant damage to the biota. Considerable attention has been given very recently in Hawaii to the potential impacts on the marine environment of blasting, both offshore and on land close to the shore. Reference in this regard should be made to supplemental discussions and permit requirements for the West Beach Project on the Island of O`ahu and the Waikoloa project on the Island of Hawai`i.

Flora. Previous surveys (AECOS, 1980; Dames & Moore, 1985) have generated fairly extensive lists of the algae to be found in this reef environment. It is not unusual for the structure and diversity of algal assemblages in a given area to change in response to seasonal changes in water temperature, wave and swell, and grazing pressure by mobile herbivores. Thus, while differences in species dominance and overall algal abundance were noted between the present survey and earlier studies, these differences are to be expected. In the present survey, overall algal abundance was noted to be greatest near shore (Stations 5 and 9). Algal diversity was also highest in this area. Algal cover was generally sparse at most offshore stations, and usually dominated by Codium edule, Asparagopsis taxiformis, and Jania sp. Midreef areas harbored Hypnea cervicornis, Halimeda opuntia, and Padina japonica in addition to the dominant species found off the reef margin. Nearshore areas harbored turf-forming species and fine-branching, calcareous red algae (e.g., Jania, Corallina, and Ceramium) which tend to trap sediment on the limestone substrata (numerous references to sand trapped by algae in this area occur in AECOS, 1980). Large masses of Hypnea cervicornis, unattached to the bottom but composed of many intertwined thalli, were seen in inshore areas. Additional species observed between the mid-reef and inshore stations (and not recorded in the transect surveys) include Hypnea multiformis, Laurencia nidifica, Sargassum obtusifolum, and Wrangelia penicillata.

A number of the species of algae (limu) observed are edible forms (e.g., Codium edule, Asparagopsis taxiformis, Laurencia nidifica; see Abbott and Williamson, 1974). Although limu gathering is popular off the `Ewa coastline, this activity is concentrated east of One`ula Beach Park (i.e., off `Ewa) rather than west (i.e., the project site). The relatively rapid increase in depth from the shore and the generally turbid water off the project site make conditions poorly suited to limu collecting.

Corals. Although scattered coral heads occur off shore of the project site, coral cover and diversity are very low. The considerable amount of fine sediment moving across the bottom would render much of the hard substrata nearshore unsuitable for hermatypic corals. A summary of the quantitative transect data is provided in Table 10. From these data it can be seen that coral cover is highest behind the reef margin (Stations 3 and 7) and in localized areas off the reef front (as typified by Station 2). Although in the area of the reef margin the rose coral, Pocillopora meandrina, is a significant component in the assemblage, species diversity is low everywhere: the assemblages surveyed are singularly dominated by encrusting heads of Porites lobata.

The effects of wave generated water motion on benthic communities will decrease with increasing depth. A decrease in the frequency of prostrate growth forms in the corals surveyed in this study was evident at deeper more offshore stations (Stations

1,2 and 6). Prostrate growth in corals is usually associated with high energy conditions. Similarly, coral coverage appears to increase with depth and their importance is probably greater seaward of the proposed channel termini.

TABLE 10.

Summary of the quantitative surveys carried out at 9 stations offshore of the proposed Ewa Marina, `Ewa, O`ahu. Stations 1 through 5 are situated on the proposed East Channel Aignment and Stations 6 through 9 on the proposed West Channel Alignment.

Station No.	Approximate Distance to shore (m)	Depth (m)	Mean Coral Coverage (%)	No. of Fish Species	No. of Individual Fish	No. of Invertebrate Species
1	800	6.1	0.6	6	18	3
2	800	7	14.7	21	57	3
3	640	2	1.1	8	48	6
4	240	2.5	0.9	4	18	4
5	60	2.1	0	4	28	3
MEAN STATIONS 1-5		3.9	3.5	8.6	33.8	3.8
6	900	7.6	4.4	18	69	3
7	670	4.3	11.7	6	26	5
8	220	3	0.1	2	3	4
9	120	2.4	0.3	13	70	4
MEAN STATIONS 6-9		4.3	4.1	9.8	42	4.0

Of all the "major" components of reef communities, hermatypic corals are usually thought of as among the more sensitive to sediment impacts from channel dredging. However, a prominant characteristic of the existing reef environment off of the Ewa Marina Community site is an abundance of very fine, easily suspended material. Thus, the reef biota in this area is presently experiencing significant impacts from turbid water and the movement from place to place of fine sedimentary material. During channel construction turbidity and sediment deposition may be enhanced in local areas (e.g., the plume of highly turbid water at and downstream of the dredging operation). However, the long-term impacts attributable to construction become difficult to assess, because stresses associated with fine sediments have been (and presently are) a part of this environment. Further, measuring construction impacts against this historical background is likely to be difficult because biological elements sensitive to sediment impacts are not present.

The assessment of the long-term impacts from the dredging project will benefit only a little from comparison with similar or related activities in the marine environment. For example, at the Barbers Point Deep-Draft Harbor project significant impacts were limited to a relatively small area surrounding the dredged entrance channel (AECOS, 1985). The impact on reef corals off Ewa Marina would seem to be potentially less than that observed off the Deep-Draft Harbor, if only because the coral assemblages are less developed and already stressed by sedimentary impacts off `Ewa. That sedimentary impacts do not always produce significant damage was demonstrated by Dollar and Grigg (1981) who investigated a spill of nearly 5 million pounds (2,200,000 kg) of kaolin clay on a reef community at French Frigate Shoals resulting from the grounding on the reef of the freighter "Anangel Liberty". These authors concluded that the actual environmental impact of the event was minor and highly localized. In this case, wave action and currents removed most of the clay from the reef in a relatively short time. Also, the morphology of the corals at the grounding site, lobate or sturdy branching, reflect the normal physical stresses impinging on this reef environment. These forms are best "adapted" to surviving short-lived sediment deposition (Bak, 1978).

Branching corals (such as *Pocillopora meandrina*) may be broken or separated from the bottom by the forces generated by an explosive charge set-off in the reef limestone. In general, prostrate and massive forms (such as *Porites lobata*) are more immune to blast damage outside of the immediate area of substratum destruction. However, observations (reported in AECOS, 1985) off the Barbers Point Deep Draft Harbor indicate some damage to massive coral heads within 100 meters of blast sites.

Other Invertebrates. Aside from corals, attached invertebrates which occur mostly throughout the survey area include sponges (most common is *Iotrochota protea*) and small anemones (*Aiptasia pulchella*). The small mussel, *Brachidontes crebristriatus* is exceptionally abundant in inner reef areas (see also AECOS, 1980). A number of echinoderms occur in moderately high densities in different areas. Concentrations of *Tripneustes gratilla* are particularly noteworthy. Near the reef margin, *Echinometra mathaei* is abundant. In predominantly sand bottom areas, the holothurian, *Holothura atra*, is common.

Long-term adverse impacts on these species would not be anticipated. Shifts in the nature of the substratum (hard bottom changing to soft bottom of the entrance channel) would preclude repopulation by some species in specific areas, but these changes cannot be regarded as major nor significant. Depending upon the depth of sediment accumulation in the channel bottom (which will depend upon rates of influx, settlement, and flushing), the "new" environment created may not differ appreciably from the present reef flat environment with respect to its suitability as habitat for the majority of the invertebrate species presently residing on this reef.

Fishes. Other than Station 9, the fish communities at all stations display a low diversity and abundance. Coral reef fish abundance and diversity is correlated with the degree of topographical relief (Brock, et al., 1985). Topographical relief provides shelter and feeding sites for resident fish; this substratum complexity is frequently created by coral growth and development. The environment throughout the study area hampers the development of corals and hence the fish communities. Considerable cover is available at Station 9. This shelter derives from an old, submerged beachrock formation and extensive fractures in the formation. Fishes have taken advantage of this habitat and a number of commercially important species occur in the area. Approximately 100 meters (300 feet) seaward of Station 9, low relief limestone bottom was also observed to harbor a variety ot reef fishes (although fish abundance is low). In this area the limestone is produced into thin, undercut plates, the overhangs providing shelter for the fish fauna.

In general, long-term impacts on the fish fauna will depend upon the destruction and/or creation of hard bottom and topographical relief. Changes in fish diversity and abundance are very likely to reflect the overall net change from dredging in the extent of substrata of low relief (e.g., the sandy channel bottom) and high relief (e.g., the channel edges).

Fishes, particularly those with swim bladders, are among the more sensitive of marine organisms to damage from underwater blasts. Because fish populations are generally sparse on this reet, blast damage would not be great. Limitations on the size and placement of charges can be used to substantially reduce the damage zone, and ensure that marine reptiles (turtle) and mammals (porpoise and whale) are not endangered by blasting.

Alternative alignments. This study considered the biota along two potential channel alignments. As a general observation, the reef assemblages throughout the survey areas were found to be remarkably similar in composition, and the results of earlier surveys (particularly AECOS, 1980 and Dames & Moore, 1985), although perhaps not precisely located in areas potentially subject to dredging, nonetheless provide relevant descriptions of this reef environment and its biota.

Localized differences in substratum type and benthic organisms are apparent, but differences over the length of the proposea dredging are less marked. If, for comparative purposes, the survey stations are grouped by channel (as in Table 10), a slightly greater mean overall density of benthic organisms was found to occur along the West Channel route. Thus, the data in

Table 10 support the contention that somewhat less direct impact to extant benthic communities would occur if the East Channel Alignment were dredged instead of the West Channel alignment. Avoidance of the submerged beachrock formation near shore along the West Channel alignment also would minimize benthic impacts. However, differences between reef areas representing the two alignments are not regarded as sufficient to base the selection of channel location primarily on biological considerations.

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APPENDIX 1

Results of the 20 x 4 m visual fish censuses conducted at 9 stations in the area off the proposed Ewa Marina, `Ewa, O`ahu. Numbers in the body of the table represent counts of individual fish. Totals and diversity indices (H') for each station are given at the end of the appendix.

	STATION NUMBER								
FAMILY AND SPECIES	1	2	3	4	5	6	7	8	9
ACANTHURIDAE									
Acanthurus dussumieri	1					1			4
A. leucopareius									1
A. nigrofuscus		3				10			
A. triostegus sandvicensis									2
A. olivaceus						1			
A. xanthopterus									
Naso literatus		1				2			
BALISTIDAE									
Melichthys niger		1				2			
Rhinecanthus rectangulus	1	2	3			1			
R. aculeatus						1			
Sufflamen bursa						1			
S.frenatus	2					2			
BLENNIDAE									
Plagiotremus goslinei							1		
CANTHIGASTERIDAE									
Canthigaster jactator	1	1		1		1			
CHAETODONTIDAE									
Chaetodon kleini		1							
C. miliaris									1
C multicinctus		1							
C ornatissimus		1							
CIRRHITIDAE									
Cirrhitus pinnulatus			3						
Paracirrhites arcatus		1				1			
P. forsteri							1		
DIODONTIDAE									
Diodon hystrix									1
LABRIDAE									
Bodianus bilunulatus		1							
Coris venusta	5	1	1			1			
Halichoeres ornatissimus		1							
Macropharyngodon geoffroy			1						
Anampses cuvieri									1
Stethojulis balteata		9	6	2	17	3	3		21

FAMILY AND SPECIES	1	2	3	4	5	6	7	8	9
					STATION NUMBER				
LABRIDAE Continued									
Thalassoma duperryi		8	16	2	6	4	4		26
MONACANTHIDAE									
Cantherhines sandwichiensis		2							
Pervagor spilosoma	8	15	17	13	3	28	16	2	3
MULLIDAE									
Upeneus arge								1	
Parupeneus multifasciatus		2				1			2
P. porphyreus									6
OSTRACIONTIDAE									
Ostracion meleagris		1							
POMACENTRIDAE									
Abudefduf abdominalis									1
A. imparipennis		1	1		2	1	1		
A. sordidus									1
Chromis vanderbilti		3				8			
SCARIDAE									
Scarus sordidus		1							

	STATION NUMBER								
	1	2	3	4	5	6	7	8	9
TOTAL # OF SPECIES	6	21	8	4	4	18	6	2	13
TOTAL # OF INDIVIDUALS	18	57	48	18	28	69	26	3	70
DIVERSITY (H')	1.44	2.50	1.58	0.88	1.06	2.12	1.21	0.64	1.81

APPENDIX 6

GROUNDWATER STUDY

FINAL
GROUNDWATER STUDY
PROPOSED EWA MARINA
EWA, OAHU, HAWAII
FOR MSM AND ASSOCIATES, INC.

DAMES & MOORE JOB NO. 13822-002-11

Dames & Moore

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FINAL

GROUNDWATER STUDY

PROPOSED EWA MARINA

EWA, OAHU, HAWAII

FOR MSM AND ASSOCIATES, INC.

1.0 PURPOSE AND SCOPE OF WORK

This report presents the results of our groundwater study performed for the proposed Ewa Marina development at Ewa, Oahu, Hawaii. The site is shown on the Vicinity Map, Plate 1, and the Map of Area, Plate 2.

The purpose of this study was to compile available information on geologic and hydrologic conditions at the Ewa Marina site and vicinity, and to analyze the effects of marina construction.

The following scope of work was completed:

1. Review of published geologic and hydrologic reports for the region, previous near site foundation and hydrogeologic study reports by Dames and Moore, and compilation and review of United States Geological Survey (USGS) records for drilled wells and water quality monitoring for wells in the vicinity of the site.

2. Compilation and correlation of available data, hydrogeologic analyses, and the preparation of this report.

2.0 SITE CONDITIONS

2.1 FACILITY DESCRIPTION

A comprehensive description of existing site conditions and the proposed development is contained within the project Environmental Impact Statement by Dames and Moore, dated December 5, 1985.

2.2 TOPOGRAPHY - PHYSIOGRAPHY

The proposed Ewa Marina development is located on the southern edge of the Ewa Plain, the coastal plain of southwestern Oahu.

The coastal plain in the area of the development consists of an exposed, emerged coral reef, presenting a relatively flat topography. The presence of some visible sinkholes indicates the area was originally a mini-karstic terrain. Grading has occurred throughout much of the site, particularly sugar cane areas, where a clayey silt topsoil has been imported and spread over the coral.

The site has a flat and relatively regular surface that slopes gently to the south at about 20 feet per mile.

2.3 CLIMATE

The Ewa Plain is generally dry, rarely receiving appreciable rainfall except during the winter months. Less than 20 inches of rain normally falls each year on much of the plain. Some areas of the plain, near the Waianae Range, receive between 20 to 30 inches of rainfall during an average year. Plate 3, Rainfall Distribution, Island of Oahu, indicates rainfall received by the Ewa Plain.

There are a number of rainfall gauges located on the Ewa Plain, operated by Oahu Sugar or located within Barbers Point Naval Air Station. The locations of the rainfall gauges on the Ewa Plain are presented on Plate 4. Monthly rainfall for the rain gauges are summarized in on Tables 1.1 and 1.2.

Pan evaporation data are available for a number of sites on the Ewa Plain. The locations of the pan evaporation sites are indicated on Plate 5. Pan evaporation data are summarized on Tables 2.1 through 2.3.

2.4 SOILS

The entire Ewa Marina site is classified by the Soil Conservation Service (SCS, 1972) as Coral Outcrop (CR) or Filled Land (Fd). Coral Outcrop (CR) consists of coral or cemented calcareous sand, formed in shallow ocean water during a time of higher sea level.

Within areas designated as CR, coral or cemented calcareous sand makes up 80 to 90 percent of the acreage. The remaining 10 to 20 percent consists of a thin layer of friable, red soil material in cracks, crevices, and depressions. The red soil is similar to the Mamala (MmC) series, classified as a silty clay with sand, ML-CL, under the Unified Soil Classification System.

Filled land generally refers to low lying coastal areas filled for sugar cane production.

2.5 GEOLOGY

The Ewa Plain area consists predominantly of coastal plain deposits. These deposits are an accumulation of interlayered coral reef deposits, coralline debris and alluvium that has been built up on the flanks of the Waianae and Koolau volcanoes. Since the end of eruptive activity, the area has been dominated by two processes:

1) The construction of fringing coral reefs developing on the slopes of the volcanoes just below sea level.

2) The erosion of the volcanoes and deposition of the resulting alluvium in nearshore areas.

Superimposed on these processes is the effect of sea level fluctuations. Sea level changes have occurred within the last million years (Stearns and Vaksvik, 1935) in response to variations in the abundance of glacial ice throughout the world. As a result, the coastal plain sediments are characterized by coral reef horizons at various levels, interlayered with layers of alluvium of various thicknesses. Furthermore, the character of a given coral reef may vary laterally -- generally, a coral reef is well cemented at the seaward edge of the reef and grades to less well cemented landward of the reef. In some cases, soft, fine grained lagoonal deposits are formed between the reef and the adjacent land mass. Such lagoonal deposits have relatively low permeability.

Two deep borings were drilled in the eastern part of the Ewa Plain (T-133 and T-134) by the University of Hawaii Institute of Geophysics for research purposes. Intermediate-depth borings were drilled by Dames and Moore in the western part of the Ewa Plain for proposed industrial plants (proposed Conoco-Dillingham Refinery and Reynolds Metals Plant). T-133 is about 500 feet inland of the southern coastline and T-134 is on a northerly line another 12,500 feet inland. The Conoco boring is about 1000 feet from the coast at Barbers Point, and the Reynolds boring lies 4000 feet directly north of the south coast in the same area. The locations of these borings are shown on Plate 6.

Boring T-133 penetrated through the full depth of the caprock to the underlying basement of Koolau basalt which appears at a depth of 1068 feet below sea level. Boring T-134 reached the same basement but at a depth of 490 feet below sea level, suggesting a basement slope of 2.65 degrees in the eastern Ewa Plain. In the west, the borings were too shallow (290 and 250 feet) to reach basement but correlate well with the eastern borings within the upper caprock zones.

In the top 300 feet of the caprock, three coralline aquifers and at least two sedimentary aquicludes occur. The uppermost coralline aquifer, predominantly composed of a massive porites reef, has been widely tested and is known to be highly permeable. None of the lower aquifers and aquicludes have been tested so their properties can only be guessed at. It is unlikely that the deeper coralline aquifers are as permeable as the top one. The degree of leakiness of the aquicludes is unknown.

Correlation of the logs of the test borings suggest the gross lithology, thickness and extent of the aquifers and aquicludes. For convenience the uppermost aquifer is numbered as 1 and the lower ones as 2 and 3. A similar identification is applied to the aquicludes. The subsurface geology of the Ewa Plain seaward of the inland limit of the marine sediments in the caprock is shown on three cross sections, shown on Plates 7.1 through 7.3. The cross section lines are shown on Plate 6.

<u>Aquifer 1</u> - At T-133, about 500 feet from the coast, Aquifer 1 reaches 207 feet below sea level, while at T-134, another 2.5 miles inland, it ends 100 feet below sea level. The aquifer ranges from 80 to 140 feet thick at Reynolds and Conoco, respectively. Within this aquifer, a thin clay layer appears at Reynolds and T-134, apparently thickening inland. Although it may be widespread, this thin layer apparently does not affect the regional hydraulic characteristics of the main aquifer. This aquifer is highly permeable and in the east is heavily pumped for irrigation. An average of 20 mgd having 700 to 1000 mg/l chloride is pumped on an annual basis. The limestone must be extremely permeable to be able to sustain such high pumping rates. No indications exist that the intrinsic hydraulic properties of the aquifer change over the region in which active wells are located.

<u>Aquiclude 1</u> - A clayey silt layer having a uniform thickness of about 40 feet lies below the massive reef composing Aquifer 1. Like the upper aquifer, this aquiclude is a distinct horizon everywhere in the Ewa Plain caprock. In the west it appears to consist of calcareous (limy) silt near the coast and terrestrial-calcareous (limy) clayey silt further inland. In the

east it consists predominantly of terrestrial brown clayey silt both near and inland of the coast. Little is known of the hydraulic characteristics of this stratum, in particular whether it behaves as a true aquiclude or as a leaky aquitard.

Lower Aquifers and Aquicludes - The lower aquifers are generally thinner and tend to have increasing silt content with distance inland. The logs suggest a depositional environment ranging from a barrier reef near the present coastline to lagoonal conditions further inland. The lower aquifers are probably an order of magnitude less permeable than Aquifer 1.

The lower aquicludes appear to range from lagoonal fines in the western Ewa Plain to brown terrestrial sediments in the eastern Ewa Plain. The aquicludes in the eastern part of the Plain are dominated by alluvial sediments deposited by the large streams draining Central Oahu. The drowned valleys of these streams form the present Pearl Harbor Lochs.

2.6 GROUND-WATER CONDITIONS

2.6.1 General

The majority of the hydrogeological studies on Oahu were carried out by the USGS in collaboration with other agencies, such as the Board of Water Supply (BWS), the Department of Land and Natural Resources (DLNR), the Department of Health (DOH), and the University of Hawaii.

Although earlier efforts can be traced as far back as the early part of the century, Stearns and Vaksvik (1935) is the first comprehensive study of the geology and ground-water resources of the island of Oahu. Stearns and Vaksvik's work is considered to be the basis of numerous subsequent studies, examples of which are Wentworth (1951), and Visher and Mink (1964). These early hydrogeologic studies of the island identify the geological setting which lead to understanding the occurrence of the basal ground water of Oahu.

More recently, growing concern with the overtapping of ground-water resources has led to studies which deal with ground water quality. Mink (1961) examines the geochemical aspect of sea water intrusion in Oahu. Dale (1967) deals with land use and its effect on the basal water supply.

The above sources are important to the present study because of their discussion of the general hydrogeological processes applicable to Oahu, and therefore to the Ewa Plain area.

Recent studies by the Corps of Engineers deal with the impact of enlarging Barbers Point Harbor on the basal water. Dale (1968) discusses the probable effect on ground-water reservoirs by enlarging the harbor, and Williams (1976) deals with the ground-water leakage in the vicinity of the proposed harbor. Dames & Moore was engaged in several studies in the Campbell Industrial Park, which involved the logging and sampling of subsurface materials, the installation of waste-water injection wells, and general foundation recommendations. The studies have led to a better understanding of the subsurface conditions and the identification of near surface aquifers in the area. Another useful source of hydrologic information is the USGS, which has maintained a record of the wells drilled in the area. USGS Report R48 (Swain, 1973) contains valuable information on the chemical quality of ground water.

2.6.2 Aquifers

A schematic representation of the aquifers of the Ewa Plain is shown on Plate 8. Two water-carrying systems are present: the deeper highly permeable volcanic aquifer which is more or less insulated from direct flushing by seawater, and the shallower less permeable interlayered coralline aquifers which are hydraulically connected to the ocean and are subject to tidal motion and mixing with seawater, particularly near the shoreline.

Volcanic Aquifer - The presence of a probable erosional layer on the volcanics, and the relatively low permeability (relative to the volcanic rock) of the coralline and alluvial sediments making up the Ewa Plain, has resulted in the formation of a relatively thick lens of fresh water within the volcanic rock. The fresh water floats on salt water in general conformance with the Ghyben-Herzberg approximation. A transition zone, consisting of increasingly brackish water separates the fresh and salt water. Recharge to the volcanic aquifer occurs by infiltration of rain water in mountainous areas. Leakage of fresh water from the volcanics is limited by the large thicknesses of confining sedimentary materials in this area, resulting in the buildup of hydraulic head and corresponding fresh-water lens thickness within the volcanic aquifer. This confinement results in artesian conditions within the fresh-water lens of the volcanic aquifer.

The volcanics directly under the site are estimated to be at a depth of about 1000 feet, based on the Hawaii Institute of Geophysics deep borings. Despite the fresh water encountered further inland, the water within the volcanics directly under the site is probably either salt water or very brackish (see Plate 8).

Coralline Aquifers - Coralline aquifers are found within the sequence of coralline and alluvial materials which make up the "caprock". Within the coralline aquifers, the majority of the water found is salt water. Relatively fresh and brackish waters are found at shallow depths within the uppermost coralline aquifer, as a thin lens floating on the salt water, also in general conformance with the Ghyben-Herzberg approximation. Near the shoreline the relatively fresh ground water becomes increasingly brackish due to the mixing action induced by tides and direct hydraulic connection with the ocean.

Excess irrigation water is the most important source of the shallow relatively fresh ground water within the uppermost coralline aquifer. A water balance analysis (Appendix A) based on areas under irrigation indicates that irrigation accounts for most of the water flowing within the thin fresh ground-water lens.

Rainfall infiltration and subsequent recharge to the uppermost coralline aquifer is limited, due to the low rainfall and the high evaporation potential within the plain. Discharge (leakage) of fresh water from the volcanics is limited to the mauka boundary of the Ewa Plain, where the fresh/brackish-water lens of the two aquifer systems coincide. Possible leakage from the volcanics in other areas becomes mixed with salt water found at depth within the caprock, and does not affect the upper thin lens of relatively fresh and brackish water.

2.6.3 <u>Ground Water Use</u>

Wells have been developed for agricultural purposes in the eastern Ewa Plain. The existing wells are depicted on Plate 9, and available data on the wells is tabulated on Table 3.

The total draft of the above wells for 1984 was 19.2 MGD (Mink, 1986).

2.6.3 <u>Flow Directions and Gradients</u>

Flow direction of the lens of fresh to brackish water within the uppermost coralline aquifer is generally toward the coastlines. In the vicinity of the site, ground-water flow would normally be influenced by the presence of the southern coastline. Flow at the site, however, is also influenced by the existing irrigation water supply wells.

Only the lens of fresh to brackish ground water is flowing. The salt water below the fresh ground water is essentially static, although there is a very slow circulation of the salt water induced by the movement within the fresh-water lens.

Water level (static head) measurements of the shallow ground waters are erratic and individual measurements are often unreliable due to the large influence exerted by the tides. Static water levels in the vicinity of the site are on the order of less than a foot to two feet, generally of the same magnitude as the tidal fluctuations. Water levels measured at various borings for the proposed development are presented on Plate 10.

Fresh to brackish ground-water flow is normally discharged at or near the shoreline. The flow rate to the ocean is estimated to be about 230 gallons per day per foot of shoreline (GPD/ft), based on hydraulic gradient data and based on an estimated hydraulic conductivity of 5,000 feet/day (Mink, 1986).

A second estimate of the ground water flow rate was made based on estimated irrigation water application rates for sugar-cane fields located within the sedimentary plain and estimated evapotranspiration rates for sugar-cane fields. An irrigation water recharge rate of approximately 420 gallons per day per foot of shoreline (GPD/ft) was calculated using this approach. The latter analyses are presented in Appendix B.

2.6.5 <u>Hydraulic Properties</u>

Tidal response and salinity profile data were gathered by the Corps of Engineers within test borings for the proposed Barbers Point Harbor. The data are summarized on Table 4. The tidal response data was used to evaluate the regional hydraulic conductivity of the coralline materials. Plate 11 presents the plotted tidal amplitudes and presents an analysis of the regional hydraulic conductivity of the coralline materials. Based on this analysis, the average horizontal hydraulic conductivity of the uppermost coralline aquifer would be approximately 1.4 centimeter per second (cm/sec) or 4000 feet/day.

This value is close to an often used estimate of 5,000 feet/day for the upper coralline aquifer of the Ewa Plain (Mink, 1986).

Although pumping test or injection test data are listed for some wells developed on the Ewa Plain, these are generally single well tests conducted to measure specific capacity (either discharge or injection capacity). Specific capacity is often as much a function of the well construction or testing method as a function the aquifer properties. Observation wells, which would allow accurate measurement of aquifer response, were not generally installed.

The effective porosity of the coralline aquifers varies over short distances but on both a regional and local scale probably averages 10 percent. An effective porosity value of 10 percent has generally been used for hydrogeologic analyses for coralline aquifers in the Ewa Plain (Williams, 1976) and on Guam (Mink, 1976). Recent pumping tests, conducted by Dames and Moore, indicate storativity values (equivalent to effective porosity in unconfined aquifers) ranging from 5 to 14 percent for coralline aquifers in downtown Honolulu.

2.6.6 <u>Ground Water Quality</u>

The ground water within the upper coralline aquifer of the Ewa Plain consists of a thin lens of relatively fresh water flowing over relatively static salt water. The thickness of the fresh-water lens varies with the hydraulic head, in conformance with the Ghyben-Herzberg approximation. As the shoreline is approached, the hydraulic head and lens thickness decrease.

Rather than a sharp interface between the fresh and salt waters, there is normally a transition zone where the water becomes increasingly brackish with depth. The transition zone can be very narrow in undisturbed and inland portions of the aquifer. The transition zone becomes larger where the aquifer has been disturbed by pumping or as a result of mixing induced by tidal action as the shoreline is approached. Adjacent to the shoreline, the high hydraulic conductivity and direct hydraulic connection to the ocean result in sufficient tidal-induced mixing that the entire lens becomes a transition zone with water normally considered brackish.

For this study, chloride levels were measured at operating Oahu Sugar wells. This data is compared on Table 5 with some data presented by Swain (1973) for the period 1958-1970 and by the Board of Water Supply (1983) for the period 1976-1980.

The data show generally increased chlorides, indicating that the effects of conversion to drip irrigation are being felt. Chloride levels are expected to increase as the aquifer slowly adjusts to the decreased input of water due to the conversion.

Percolating irrigation water also has a marked effect on the shallow waters of the Ewa Plain (Mink, 1962). Large quantities of soluble nitrates from fertilizers and silicates leached from the soil are picked up by the percolating irrigation water. Swain (1973) notes that some sulfate originating from fertilizers can also be picked up by the percolating waters. Large quantities of orthophosphate also enter the percolating irrigation water but most of the phosphate is rapidly fixed by lateritic soil (Swain, 1973).

Much of the relatively fresh ground-water recharge is from sugar-cane irrigation. Conversion to more efficient drip irrigation techniques has recently been completed. The effect of drip irrigation would be to reduce the amount of excess irrigation water, resulting in less ground-water flow and high chloride content of the lens water. As quantities of fertilizers and other nutrients are probably applied at the same rate, the conversion to drip irrigation would also tend to increase the concentrations of nitrates and phosphates in the ground water.

Recent nitrate data is presented on Table 6. A significant increase in nitrates is indicated over the past year. Because of the significant increase, the 1986 values were confirmed by retesting of the samples at the same lab which performed the 1985 tests, and by using blind spiked samples at both labs as a quality control measure. The retesting and quality control measures show the 1986 results are accurate.

3.0 HYDRAULIC ANALYSES

3.1 GENERAL

To analyze the effects of Marina construction, a computer model was applied. A description of the model and the application is presented in Appendix C.

The ground-water system to which the model is applied, the thin Ghyben-Herzberg lens within the upper coralline aquifer, is in a state of transition due to the relatively recent changeover to drip irrigation by Oahu Sugar. For simplification, the analysis was confined to a steady state analysis, but the effects of the change to drip irrigation were also analyzed to account for the relative effects of the two factors on the ground-water system. It is anticipated that the effects of the change to drip irrigation will not be fully realized for many years. Therefore, the effects of marina construction will occur at the same time as the effects of drip irrigation.

3.2 COMPUTER MODELING

Steady state solutions for four cases were analyzed:

1. Furrow irrigation and pre-marina installation
2. Drip irrigation and pre-marina installation
3. Furrow irrigation and post-marina installation
4. Drip irrigation and post-marina installation

For the above cases, the relative changes in head at the seven irrigation well locations and at five observation points (See Appendix C) were analyzed. The results of the analyses are presented on Table 7.

The analyses indicates an absolute value of head change ranging from approximately 0.05 to 0.17 feet due to construction of the Marina, with the variation primarily due to varying distance from the proposed Marina. The head change versus distance from the Marina is plotted on Plate 12. This compares with absolute head change values ranging from approximately 0.19 to 0.95 feet due to the change from furrow to drip irrigation.

Percentage changes due to marina construction range from approximately 0.2 to 7.7 percent of those due to the implementation of drip irrigation.

3.3 ANALYTICAL SOLUTION

Analyses were performed to check on the rate of decay of head as a result of the change to drip irrigation. For these analyses, an analytical model which treats the caprock aquifer as a single cell having an initial head (steady state for furrow irrigation) of 2.0 feet was used. Replacement with drip irrigation will cause the new steady state head, h_e to go to 1.07 feet with half the head loss taking place in the first 1.5 years and steady state being approached in approximately 8 to 10 years. The rate of head decay is plotted on Plate 13.

The applied analytical model is described by Board of Water Supply (1980), and was previously applied to the basaltic aquifers of southern Oahu.

3.4 EFFECTS ON IRRIGATION WELLS

Available information on the irrigation wells are tabulated on Table 3. As indicated by the above analyses, significant changes in the flow, heads, and therefore water quality are occurring within the caprock aquifer, as a result of the change to drip irrigation. This is supported by recent water quality data taken during this study, which indicates that salinity and nitrates are at higher levels than previously measured.

It is anticipated that further degradation of the water quality will occur as the longer term effects of the change to drip irrigation are felt.

The analyses indicate that the marina construction will result in a limited amount of additional head reduction. The effects on the amount of water available and the quality of the water, resulting from the marina, are not believed to be significant, for the following reasons:

1. The head reductions due to marina construction are approximately an order of magnitude less than those due to conversion to drip irrigation.

2. The head reductions due to marina construction are due to a reduction in flow length, while the reductions due to drip irrigation are due to a reduction in the quantity of flow. For a given flow rate, a reduction in flow length results in lower heads since as the flow length is decreased, the water would flow faster within a thinner lens over a shorter flow path. For an equal reduction in head, a head loss due to a flow length reduction would have much less effect on water quantity and quality than a reduction due to decreased flow.

3. The construction of the existing wells (see Table 3) is such that only the uppermost portions of the fresh water lens are skimmed. Bottom of hole elevations range from -3 to -6 feet Mean Sea Level, while heads indicate a lens thickness of approximately 80 feet. Although there are small head reductions due to marina construction, the quality of ground water extracted by this method would not be affected, particularly as the total quantity of flow remains the same.

3.5 GROUND-WATER FLOW EFFECTS ON MARINA

Excavation of the marina will be identical to shifting the sea coast inland, as if a new embayment were created by natural processes. Excavation will not affect the basic structure of the aquifer. The relatively shallow excavation, also, will not affect the ability of the approximately 1,000-foot thick sedimentary/alluvial deposits to act as an effective caprock over the deep basalts.

Ground-water flow into the marina, at steady state, will be determined by the inputs to the ground-water system. Existing flow rates are estimated at approximately 230 to 420 gallons per day per foot of existing shoreline. Inflow into the marina would approximate this in the long term given constant conditions, however, ground-water flow rates are in a state of transition due to the effects of conversion to drip irrigation. It is anticipated that ground-water flow rates will decrease.

The ground-water flow would be initially greater than the steady-state flow, as there will be a transition period while ground water in storage in the near vicinity of the marina drains. However, we anticipate that much of this transition would occur during the relatively extended period of dredging of the marina.

4.0 CONCLUSIONS

1. A comprehensive groundwater study of the Ewa Plain has been conducted to to compile available information on geologic and hydrologic conditions at the Ewa Marina site and vicinity, and to analyze the effects of marina construction. The study included compilation of available data on site topography, climate, soils, geology, and ground-water parameters.
2. The sedimentary caprock extends to depths of approximately 1000 feet at the Ewa Marina site, overlying Koolau Basalts. In the top 300 feet of the caprock, three limestone aquifers and at least two sedimentary aquicludes occur. The uppermost limestone, predominantly composed of a massive porites reef, has been widely tested and is known to be highly permeable. It is unlikely that the deeper limestone aquifers are as permeable as the top one.
3. Within the coralline caprock aquifers, the majority of the water found is salt water. Relatively fresh and brackish waters are found at shallow depths, as a thin lens floating on the salt water, in general conformance with the Ghyben-Herzberg approximation. Near the shoreline the relatively fresh ground water becomes increasingly brackish due to the mixing action induced by tides and direct hydraulic connection with the ocean.
4. Excess irrigation water is the major source of the shallow relatively fresh ground water within the coralline aquifer. Rainfall infiltration, and leakage of fresh water from the volcanics at the boundary of the Ewa Plain, comprise the remainder of the ground-water flow.
5. Wells have been developed for agricultural purposes in the eastern Ewa Plain. The total draft of the wells for 1984 was 19.2 MGD.
6. Ground-water flow is estimated to be about 230 to 420 gallons per day per foot of shoreline (GPD/ft).

7. The average horizontal hydraulic conductivity of the upper coralline caprock aquifer is estimated to be approximately 1.4 to 1.8 cm/sec or 4000 to 5000 ft/day.

8. Percolating irrigation water also has a marked effect on the shallow waters of the Ewa Plain (Mink, 1962). Large quantities of soluble nitrates from fertilizers and silicates leached from the soil are picked up by the percolating irrigation water.

9. An effect of the conversion to drip irrigation, which reduces the amount of excess irrigation water, is less ground-water flow and higher chloride content of the lens water.

10. A ground-water computer model was applied to analyze the effects of Marina construction and the effects of drip irrigation. Percentage changes in head due to marina construction range from approximately 0.2 to 7.7 percent of head changes due to the implementation of drip irrigation.

11. Analysis of the rate of head decay due to drip irrigation indicates that half of the loss occurs in the first 1.5 years, and steady state is approached in approximately a decade.

12. Marina construction is not expected to affect the amount or quality of water available at existing irrigation wells, for the following reasons:

    a. The head reductions due to marina construction are approximately an order of magnitude less than those due to conversion to drip irrigation.

    b. The head reductions due to marina construction are due to a reduction in flow length, while the reductions due to drip irrigation are due to a reduction in the quantity of flow.

    c. The construction of the existing wells is such that the quality of ground water extracted would not be affected.

13. Water quality at the existing wells will degrade in the future, but this will be due to residual effects of the change to drip irrigation.

14. Marina construction would shift the sea coast inland, but would not affect the basic structure of the aquifer or the ability of the caprock to confine the much deeper basalt.

15. Ground-water flow into the marina would approximate the existing ground-water flow, with some long-term reduction anticipated due to the conversion to drip irrigation. The initial flow into the marina would be higher due to the release of ground water from storage, but this is mitigated by the relatively extended marina dredging period.

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DAMES & MOORE

Respectfully submitted,

Masanobu R. Fujioka, P.E.
Certified Professional Hydrologist #107
American Institute of Hydrology

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OAHU RAINFALL
(INCHES)

STATE KEY NO.	GAGE NAME	RECORD YEARS	ANNUAL MEDIAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
700.00	WAIMANALO (EWA)	71	19.4	2.9	1.7	1.2	0.5	0.4	0.1	0.2	0.2	0.4	0.8	1.3	2.2
701.00	BARBERS POINT	19	18.3	3.4	1.9	1.1	0.4	0.4	0.1	0.2	0.7	0.2	0.8	0.9	2.3
702.00	US MAGNETIC OBS	57	19.0	2.0	1.6	1.4	0.8	0.3	0.1	0.2	0.3	0.4	0.6	1.1	2.4
702.20	OBSERVATORY	14	23.5	3.9	2.0	2.2	1.0	0.6	0.2	0.4	0.2	0.5	1.6	1.9	2.3
703.00	HONO WB AIRPORT	29	24.0	3.6	2.4	1.5	0.7	0.4	0.2	0.3	0.4	0.6	1.2	2.1	2.6
704.00	HONO SUBSTATION	70	25.5	2.8	2.1	2.1	1.3	0.7	0.5	0.6	0.8	0.9	1.4	2.0	2.7
705.00	BERETANIA PUMP	25	29.2	4.0	2.4	2.5	1.7	0.9	0.7	1.0	0.7	1.0	1.9	2.5	3.4
705.20	NUUANU VALLEY	39	41.0	3.2	4.1	3.1	2.9	2.3	1.8	2.2	2.0	2.1	2.3	3.9	3.8
705.40	US NAVAL STATION	37	24.0	2.2	2.1	2.1	1.3	0.8	0.6	0.7	0.8	1.1	1.4	2.0	3.1
705.50	HONOLULU-BROWN	10	31.9	2.7	4.5	1.7	1.6	1.1	0.8	0.8	1.1	0.6	2.1	3.0	2.0
705.70	HONO PAUOA VALL	10	41.6	3.1	4.7	2.9	2.3	2.2	2.0	2.1	2.0	1.7	3.1	3.5	3.1
705.80	HONO MILLERGHER	16	31.8	2.7	3.4	1.8	2.3	1.4	0.8	1.0	1.3	1.1	1.6	3.2	2.5
706.00	PACIFIC HEIGHTS	47	69.0	6.5	4.8	6.7	4.9	4.7	3.9	5.5	4.5	4.0	4.6	5.9	6.1
706.30	KINAU STREET	39	29.2	2.4	2.6	2.3	1.7	1.0	0.7	0.8	1.0	1.7	1.4	1.9	2.8
707.00	MAKIKI	58	36.6	4.2	2.8	3.5	2.4	1.5	1.3	1.7	1.8	1.7	2.6	3.2	3.8
707.20	HONOLULU PUNAHOU	21	37.3	2.7	4.0	2.4	2.4	1.6	1.4	1.6	1.7	1.6	2.4	3.3	3.5
707.30	ALIHILANI	25	52.4	5.9	4.4	5.2	4.2	2.9	2.0	2.9	2.4	2.7	3.4	5.2	6.6
709.00	PUNCHBOWL CRATER	24	38.0	4.8	3.0	3.7	2.8	1.4	1.1	2.1	1.5	1.4	2.5	3.9	4.6
710.00	NUTRIDGE	45	77.3	6.4	5.1	7.0	6.4	5.1	4.3	5.9	6.1	4.3	5.2	7.1	8.6
710.10	CLEMENTS	29	110.6	9.4	7.2	10.2	9.6	7.5	5.8	9.0	8.1	6.0	7.2	10.2	9.6
711.00	DOLE-PRI	28	35.9	3.8	3.0	3.4	2.5	2.1	1.2	1.8	1.9	1.3	2.1	2.9	4.2
711.10	KAIMUKI PUMPING	26	25.9	3.6	2.2	2.3	1.5	0.5	0.4	0.7	0.5	0.6	1.1	2.7	3.1
712.00	MANOA-KELLER	57	57.9	8.5	4.0	5.3	4.0	3.5	2.9	3.4	3.8	3.0	4.2	5.3	5.6
712.10	MANOA-BEAUMONT	16	69.1	6.3	6.4	6.1	4.3	4.4	2.8	4.1	4.8	3.6	4.2	4.9	5.5
712.20	OAHU AVENUE	12	100.5	7.9	7.8	8.1	6.8	7.2	5.4	7.0	7.0	4.8	6.2	8.4	10.2
713.00	UNIV OF HAWAII	56	38.3	4.4	2.9	3.7	2.5	1.7	1.3	1.9	2.0	1.8	2.7	3.4	3.6
714.00	TANTALUS-UHOPSKI	55	102.7	7.3	6.8	9.8	8.2	7.2	7.3	8.7	8.5	6.5	7.1	8.9	9.4
714.10	KEAHI	27	104.2	8.5	8.1	9.9	9.2	6.6	6.1	8.2	6.9	5.8	6.8	9.4	9.5
714.20	KALIULA	21	93.4	6.0	5.5	8.6	7.5	5.8	6.0	8.1	7.1	7.6	6.9	8.0	8.4
715.00	WAIALAE-TINKER	53	26.2	3.4	2.4	1.9	1.5	0.8	0.4	0.7	0.7	0.8	1.4	2.1	2.3
716.00	MANOA TUNNEL 2	48	140.8	10.3	9.2	11.8	12.2	10.8	9.7	12.1	11.2	8.0	9.7	12.1	11.2
716.10	WOODLAWN-CARTER	12	85.5	6.8	8.5	7.5	6.5	5.3	3.9	6.6	7.1	4.5	6.5	7.6	9.0
716.20	MANOA-DESKY	15	89.2	5.8	5.4	7.9	7.3	7.4	5.9	5.5	7.5	6.1	5.3	8.2	7.1
716.70	WAAHILA	10	68.1	6.0	5.0	6.4	5.4	4.4	4.2	5.4	4.6	3.8	5.1	7.0	6.3
716.80	WOODLAWN-DWS	10	134.7	11.1	8.9	6.5	14.2	7.9	9.4	11.3	9.9	9.8	7.9	7.9	7.1
717.00	BLACK POINT	41	19.7	2.6	1.8	1.2	0.9	0.4	0.3	0.4	0.4	0.4	1.3	1.3	1.8
717.10	KAPIOLANI PARK	13	23.2	1.6	4.4	1.6	1.2	0.4	0.4	0.1	0.4	0.2	1.1	1.7	1.7
717.20	WAIKIKI SHELL	11	26.4	4.1	2.3	2.5	1.3	0.7	0.2	0.3	0.3	0.6	2.0	4.5	2.6
718.00	PALOLO VY-DWS	48	138.0	9.9	9.3	11.2	12.2	10.4	8.0	10.0	9.6	7.3	8.9	10.8	11.2
718.10	OLYMPUS	15	68.1	7.1	6.6	5.1	5.7	4.4	4.5	4.3	4.9	4.4	5.5	6.0	4.9
720.00	MAISONIA DRIVE	10	48.4	4.3	4.4	4.3	3.3	2.2	1.4	2.2	2.8	1.7	2.7	2.9	5.6
721.00	WILHELMINA RISE	47	40.1	3.7	3.6	4.1	3.3	1.9	1.3	1.9	1.9	1.7	2.8	3.5	3.9
722.20	KAHALA-ARNOLD	15	25.8	2.7	2.2	2.0	1.4	1.1	0.3	1.0	0.9	0.7	1.3	1.9	2.7
722.50	WAIALAE-PAUL	10	24.5	6.6	3.0	2.6	1.3	0.9	0.1	0.3	0.3	0.6	2.0	5.2	2.2
723.00	WAILUPE	28	27.1	2.9	1.9	1.9	1.7	1.0	0.6	1.1	1.0	0.9	2.1	1.8	2.3

DLNR, 1973
1/2

TABLE 1.1

DLNR, 1973
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OAHU RAINFALL
(INCHES)

STATE KEY NO.	GAGE NAME	RECORD YEARS	ANNUAL MEDIAN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
723.10	WAILUPE MAUKA	12	32.1	4.1	2.5	2.1	2.2	1.4	0.7	1.6	0.9	1.4	2.9	2.5	2.8
723.20	WAILUPE HCS 170	14	44.5	4.5	4.5	6.0	3.1	2.2	1.4	2.1	2.1	1.8	2.9	3.6	6.4
723.30	AINA HAINA	10	35.8	4.2	3.1	3.4	1.9	1.4	0.6	1.1	1.4	1.0	1.9	2.6	4.0
723.40	PAIKO DRIVE	16	29.5	5.4	2.9	3.2	2.6	1.4	0.7	1.4	0.9	1.1	1.8	3.2	3.7
723.70	AINA HAINA LOWER	10	33.2	6.9	3.0	2.8	2.4	1.6	0.6	1.2	1.0	1.0	2.2	3.8	4.1
724.00	MAKAPUU POINT	62	26.1	2.7	2.1	2.8	1.4	0.6	0.4	0.5	0.6	0.5	1.2	1.5	2.6
724.20	LUNALILO HOME	11	31.4	4.1	2.3	2.7	2.0	1.2	0.3	1.4	0.7	0.6	2.0	2.4	3.8
724.40	PORTLOCK ROAD	10	32.6	8.3	2.3	3.2	2.4	1.0	0.5	1.1	0.6	0.8	2.1	1.9	4.1
725.00	NIKILUA	26	19.8	1.9	1.6	1.5	1.1	0.6	0.3	0.2	0.5	0.5	1.4	0.9	1.8
725.20	HAKULOA	26	44.0	7.0	3.4	3.5	1.9	1.6	1.0	1.3	1.0	1.0	2.2	3.3	5.1
726.00	OPD	49	20.9	3.1	2.2	1.4	0.5	0.6	0.1	0.2	0.1	0.6	0.8	1.6	2.2
727.00	PUMP 10 (EWA)	64	20.4	3.0	1.6	1.5	0.6	0.4	0.1	0.2	0.2	0.4	0.9	1.1	2.4
729.00	FIELD 05-06	15	37.1	4.3	4.2	2.5	1.2	0.5	0.4	0.6	1.2	0.6	1.2	1.5	5.1
729.10	FIELD 86-CPC	13	31.1	4.5	3.2	1.7	0.7	0.4	0.3	0.5	1.0	0.5	0.9	1.1	4.0
730.00	RESERVOIR 60	49	22.5	3.1	2.1	1.5	0.6	0.6	0.2	0.3	0.3	0.4	1.0	2.0	2.2
731.00	FIELD 151	24	25.5	3.1	1.7	1.6	1.1	0.6	0.2	0.4	0.6	0.7	1.3	2.6	2.3
732.00	RESERVOIR 6	71	21.4	2.9	1.6	1.5	0.6	0.4	0.1	0.3	0.4	0.5	0.8	1.6	2.4
733.00	FIELD 105	56	28.3	3.5	2.0	2.1	1.1	0.6	0.3	0.4	0.5	0.5	1.3	1.8	2.7
733.10	FIELD 120	10	33.3	8.8	3.7	2.0	1.4	1.0	0.4	0.6	0.3	0.8	2.1	4.1	2.3
734.40	FIELD 130	10	35.3	6.7	3.8	2.1	1.7	1.3	0.4	0.5	0.3	0.9	2.3	4.2	2.5
735.00	FIELD 43	49	22.5	3.1	2.3	1.6	0.5	0.7	0.2	0.3	0.3	0.4	0.9	2.1	2.0
736.00	RESERVOIR 8	71	23.0	2.8	2.1	1.6	0.8	0.5	0.2	0.3	0.4	0.5	1.0	1.8	2.5
737.00	RESERVOIR 9	51	24.6	3.1	2.0	1.7	0.8	0.6	0.3	0.4	0.4	0.5	1.3	1.9	2.3
738.00	FIELD 165	21	35.1	4.8	3.2	3.8	1.6	1.3	0.4	0.9	0.9	0.7	2.2	2.9	4.4
738.10	FIELD 57	12	33.8	3.6	3.9	2.9	1.0	0.4	0.3	0.5	1.4	0.5	1.0	2.1	4.0
738.20	FIELD 140	21	32.9	3.8	2.8	2.2	1.1	0.9	0.3	0.6	0.6	0.6	1.7	3.5	3.7
738.40	FIELD 155	10	34.6	5.1	3.3	2.3	2.1	1.4	0.3	0.6	0.4	0.5	2.1	4.0	2.3
739.00	FIELD 135	28	32.9	4.9	2.7	1.9	1.1	1.1	0.3	0.6	0.5	0.6	1.7	3.1	3.2
740.00	RESERVOIR 5	49	24.1	2.8	2.5	1.7	0.8	0.5	0.2	0.4	0.3	0.5	1.1	2.3	2.4
740.10	FIELD 220A	21	33.9	4.2	2.8	2.2	1.5	0.8	0.4	0.7	0.8	0.8	2.3	3.2	4.0
740.20	FIELD 26	16	30.2	4.3	2.3	2.1	0.8	0.8	0.3	0.4	0.6	0.6	1.5	1.3	3.4
740.40	KUNIA-HSPA	12	30.8	5.3	1.9	1.8	1.3	1.1	0.2	0.5	0.2	1.1	2.2	4.7	2.5
741.00	EWA MILL	64	21.5	2.3	2.0	1.6	0.7	0.4	0.2	0.3	0.3	0.5	0.9	1.5	2.6
742.00	PUMP 7	28	27.2	4.4	2.2	1.9	1.1	0.7	0.2	0.5	0.3	0.5	1.3	2.8	2.8
742.10	FIELD 205	28	29.7	4.4	2.5	2.2	1.2	0.7	0.3	0.6	0.5	0.6	2.2	3.0	3.0
742.30	HONOULIULI	22	21.1	3.3	1.8	1.3	0.5	0.7	0.0	0.0	0.0	0.4	1.3	2.0	2.7
743.00	RESERVOIR 2	49	24.1	3.4	2.3	1.6	1.0	0.7	0.2	0.4	0.4	0.5	1.3	2.0	2.4
744.00	FIELD 74	49	21.1	2.8	1.9	1.4	0.7	0.5	0.1	0.3	0.3	0.3	1.1	1.7	2.2
745.00	PUMP 4-D SUGAR	17	28.7	3.9	2.0	2.2	1.3	0.4	0.2	0.5	0.6	0.5	1.6	1.8	3.7
745.10	FIELD 15	16	28.1	4.3	2.4	2.1	0.9	0.4	0.3	0.5	0.7	0.5	1.8	1.5	3.3
746.00	AMOKAA	40	22.4	2.5	2.6	1.8	0.9	0.5	0.2	0.3	0.5	0.6	0.9	1.3	3.5
747.00	FIELD 62	40	22.7	3.0	2.1	1.7	0.7	0.6	0.1	0.3	0.3	0.4	0.9	1.9	2.2
748.00	FIELD 410 (290)	28	32.4	4.4	2.6	2.1	1.6	0.9	0.4	0.9	0.6	0.6	2.1	2.9	3.5
750.00	WAIPAHU-O SUGAR	78	26.4	2.8	2.3	2.3	1.0	0.7	0.4	0.5	0.6	0.7	1.3	2.0	2.6
751.00	FIELD 79.1	52	21.1	2.6	1.7	1.6	0.6	0.5	0.2	0.3	0.3	0.4	1.0	1.6	2.2

TABLE 1.2

ISLAND OF OAHU

Station No. 702 — US MAGNETIC OBSERVATORY

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1956	3.50	4.12	5.83	6.61	7.63	8.36	7.60	8.92	7.33	6.12	4.39	4.66	74.07	6.23	6.36	8.92	3.50
1957	4.37	4.66	5.47	6.32	7.50	7.54	8.37	8.22	6.49	6.27	5.22	4.38	74.81	6.23	6.29	8.37	4.37
1958	4.08	4.31	5.98	6.99	7.59	7.59	8.04	8.44	8.26	6.40	4.76	4.62	77.06	6.42	6.09	8.44	4.08
1959	4.67	4.70	7.19	7.11	9.13	9.12	8.87	8.06	7.39	6.72	4.51	5.44	82.31	6.85	7.15	9.13	4.67
1960	5.08	5.50	5.98	8.44	8.37								33.37	6.67	5.98	8.44	5.08
TOTAL	21.10	25.29	30.45	35.47	40.22	32.43	32.99	33.44	29.47	25.51	18.88	18.88					
MEAN	4.22	4.65	6.09	7.09	8.04	8.15	8.22	8.41	7.36	6.37	4.72	4.72					
MED	4.05	4.56	5.98	6.99	7.63	7.98	8.20	8.33	7.36	6.33	4.63	4.53					
MAX	5.08	5.50	7.19	8.44	9.13	9.12	8.87	8.92	8.26	6.72	5.22	5.44					
MIN	3.50	4.12	5.47	6.32	7.50	7.54	7.60	8.06	6.49	6.12	4.39	4.38					

Station No. 702.2 — US MAGNETIC OBSERVATORY 2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1960							9.06	10.04	7.96	6.68	6.29	4.51	44.52	7.42	7.31	10.04	4.51
1961	5.54	5.57	7.19	7.36	9.47	8.86	8.90	10.17	9.91	7.72	6.63	5.68	92.00	7.66	7.54	10.17	5.54
1962	5.21	4.91	5.83	7.30	7.85	8.89	10.15	9.23	8.41	7.48	6.99	4.22	86.47	7.20	7.39	10.15	4.22
1963	4.66	5.00	5.98	6.29	7.44	8.36	9.04	8.41	7.81	6.95	5.77	4.16	80.07	6.67	6.62	9.04	4.16
1964	5.65	----	6.11	6.62	8.75	8.92	8.96	9.82	9.09	8.02	5.44	4.28	81.66	7.42	8.02	9.82	4.28
1965	4.30	4.88	7.22	6.61	6.92	9.61	9.14	9.24	7.62	6.38	4.67	4.35	80.92	6.74	6.76	9.61	4.30
1966	4.25	4.19	6.08	6.96	8.04	9.35	9.26	9.07	8.19	7.04	4.83	4.43	81.66	6.80	7.00	9.35	4.19
1967	4.37	5.19	4.97	5.40	8.21	8.35	9.20	8.91	9.24	6.69	5.59	4.37	81.49	6.79	6.54	9.24	4.37
1968	3.59	3.85	4.84	6.37	7.33	8.41	9.15	9.44	7.97	5.80	4.90	3.65	75.30	6.27	6.08	9.44	3.59
1969	3.53	4.70	6.34	7.50	8.89	8.18	9.84	9.47	7.57	6.26	5.30	4.60	82.46	6.87	6.92	9.84	3.53
TOTAL	41.30	38.35	54.56	61.21	72.90	78.93	92.70	93.95	82.75	69.02	56.61	44.29					
MEAN	4.58	4.79	6.06	6.80	8.10	8.77	9.27	9.39	8.27	6.90	5.66	4.42					
MED	4.37	4.89	6.08	6.61	8.04	8.86	9.14	9.36	9.08	6.82	5.61	4.36					
MAX	5.65	5.57	7.22	7.50	9.47	9.61	10.15	10.17	9.24	8.02	6.99	5.68					
MIN	3.53	3.85	4.84	6.29	6.92	8.18	8.90	8.41	7.57	5.80	4.67	3.65					

Station No. 727 — RESERVOIR 10

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1962										7.79	7.56	4.38	19.73	6.57	7.56	7.79	4.38
1963	4.36	5.33	7.34	8.90	9.45	10.04	10.72	9.81	9.31	8.59	6.89	5.37	96.63	8.05	8.74	10.72	4.36
1964	6.61	7.71	6.72	8.27	10.44	9.71	10.20	11.02	10.04	9.80	7.02	6.01	103.55	8.62	8.99	11.02	6.01
1965	5.72	7.13	7.72	7.45	7.13	10.02	9.86	10.33	8.36	8.60	6.80	6.60	95.72	7.97	7.58	10.33	5.72
1966	6.89	4.79	7.78	6.90	8.06	10.49	10.97	10.31	9.35	8.16	6.18	5.81	96.79	8.06	8.03	10.97	4.79
1967	5.58	5.76	6.51	7.15	7.81	8.11	9.90	8.65	8.90	7.61	7.12	6.45	89.55	7.46	7.38	9.90	5.58
1968	5.58	5.53	6.94	7.36	8.68	10.40	10.23	9.99	9.30	7.53	6.39	5.80	93.73	7.81	7.44	10.40	5.53
1969	7.12	6.33	----	9.50	9.96	8.30	10.57	11.02	8.38	7.11	6.24	6.25	89.83	8.16	8.30	11.02	6.24
1970	5.93	6.51	6.70	9.64	9.35	9.32	10.77	----	----	----	----	----	60.22	8.60	9.32	10.77	5.93
TOTAL	47.77	49.66	51.73	66.27	69.88	76.39	83.22	71.13	63.64	65.19	54.20	46.67					
MEAN	5.97	6.20	7.39	8.29	8.73	9.54	10.40	10.16	9.09	8.14	6.77	5.83					
MED	5.82	6.10	7.36	8.13	8.82	9.86	10.40	10.31	9.30	7.97	6.84	5.91					
MAX	7.12	7.71	8.70	9.64	10.44	10.49	10.97	11.02	10.04	9.80	7.56	6.60					
MIN	6.36	4.79	5.51	7.15	7.13	8.11	9.86	8.65	8.36	7.11	6.18	4.38					

MONTHLY PAN EVAPORATION DATA

REFERENCE: DLNR, 1973

SIG ____ BY ____ DATE ____

FILE 113-553

CHECKED BY ____ DATE ____

DAMES & MOORE

TABLE 2.1

Station No. 732 — RESERVOIR 8

ISLAND OF OAHU

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1962	----	----	----	----	----	----	----	----	----	6.84	6.97	4.67	18.48	6.16	6.84	6.97	4.67
1963	5.15	5.27	5.99	8.20	8.84	9.91	11.14	9.98	9.34	8.56	6.35	4.43	93.12	7.76	8.38	11.14	4.43
1964	6.11	7.02	7.67	7.40	10.05	10.03	8.45	10.31	8.90	7.95	5.96	5.18	95.03	7.91	7.81	10.31	5.18
1965	5.48	6.66	7.04	6.95	6.74	10.33	9.98	10.20	8.40	7.42	6.06	5.86	91.35	7.61	7.00	10.33	5.48
1966	5.95	4.19	7.07	6.37	8.37	10.40	11.09	10.20	8.57	7.12	4.98	5.16	91.47	7.62	7.74	11.09	4.19
1967	4.94	5.37	5.64	6.85	7.42	8.61	9.37	8.86	8.36	7.39	6.64	5.91	85.37	7.11	7.13	9.37	4.94
1968	4.90	5.07	6.82	7.20	7.50	9.19	9.39	9.94	8.37	6.11	5.37	4.81	84.67	7.05	7.01	9.94	4.81
1969	5.33	5.13	----	8.10	8.20	8.42	10.29	10.59	8.27	6.73	5.61	5.78	82.45	7.49	8.10	10.59	5.13
1970	5.44	5.93	9.12	9.66	8.70	9.07	10.21						58.95	8.13	8.70	10.21	5.44
TOTAL	43.32	44.64	49.32	62.56	65.84	75.96	79.92	70.00	60.39	58.12	47.94	41.80					
MEAN	5.41	5.58	6.90	7.82	8.23	9.49	9.99	10.01	8.62	7.26	5.99	5.22					
MED	5.39	5.32	7.05	7.75	8.28	9.55	10.09	10.20	8.57	7.25	6.01	5.17					
MAX	6.11	7.02	9.12	9.66	10.05	10.40	11.14	10.59	9.34	8.56	6.97	5.91					
MIN	4.90	4.19	5.64	6.80	6.74	8.42	8.45	8.84	8.27	6.11	4.98	4.43					

Station No. 737 — RESERVOIR 9

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1962									----	6.10	6.08	4.15	16.33	5.44	6.08	6.10	4.15
1963	4.92	4.62	5.69	6.45	8.22	7.92	9.12	9.71	8.91	7.88	6.79	4.39	84.61	7.05	7.33	9.71	4.39
1964	6.09	6.71	7.07	6.35	8.21	8.83	8.56	9.18	8.09	7.94	5.13	4.87	87.03	7.25	7.50	9.18	4.87
1965	5.51	6.34	6.81	6.49	6.27	8.99	8.70	9.49	6.69	7.32	5.19	5.21	83.01	6.91	6.59	9.49	5.19
1966	5.79	6.09	6.86	7.26	7.79	9.22	9.14	8.86	7.59	6.60	4.21	5.11	82.54	6.87	7.07	9.22	4.09
1967	6.80	5.29	4.71	6.56	7.37	8.89	8.91	8.66	8.41	7.04	6.73	5.43	82.80	6.90	6.88	8.91	4.71
1968	4.31	4.98	6.02	8.86	7.47	8.58	8.58	8.98	7.44	5.64	5.28	4.77	80.91	6.74	6.73	8.98	4.31
1969	5.43	5.08	----	7.19	7.59	8.04	9.21	9.97	7.64	6.77	5.16	6.13	78.21	7.11	7.19	9.97	5.08
1970	4.59	5.76	7.38	8.09	7.52	7.59	8.82						49.75	7.10	7.52	8.82	4.59
TOTAL	41.44	42.87	44.53	57.29	60.44	68.06	71.04	64.03	54.77	55.29	44.57	40.06					
MEAN	5.18	5.35	6.36	7.16	7.55	8.50	8.88	9.26	7.82	6.91	5.57	5.00					
MED	5.17	5.18	6.81	6.88	7.55	8.70	8.86	9.18	7.64	6.90	5.23	4.99					
MAX	6.09	6.71	7.38	8.86	8.22	9.22	9.21	9.97	8.91	7.94	6.79	6.13					
MIN	4.31	6.09	4.71	6.35	6.27	7.59	8.56	8.66	6.69	5.64	4.21	4.15					

Station No. 740.3 — FIELD 200

ISLAND OF OAHU

YEAR	JAN	FEB	MAR	APR	MAY	JUN.	JUL.	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1959							7.94	9.88	7.44	5.76	4.17	4.02	39.23	6.53	6.60	9.88	4.02
1960	3.11	4.36	4.70	5.68	7.78	8.64	9.00	7.28	8.45	6.39	5.37	4.56	75.00	6.25	6.03	9.00	3.11
1961	4.36	4.64	3.78	4.91	8.41	8.16	8.96	9.46	6.91	6.51	4.84	4.83	75.57	6.29	5.71	9.46	3.78
1962	4.23	5.75	5.65	6.69	8.13	8.23	9.56	8.99	9.13	8.61	7.80	4.97	87.74	7.31	7.96	9.56	4.23
1963	5.97	4.63	5.35	4.44	6.26	8.97	9.39	11.52	7.62	6.45	5.43	3.72	82.28	6.85	6.35	11.52	3.72
1964	6.09												6.09	6.09	6.09	6.09	6.09
TOTAL	23.76	19.36	19.49	23.74	30.58	34.00	45.37	47.13	39.55	33.72	27.61	22.10					
MEAN	4.76	4.72	4.87	5.93	7.64	8.50	9.07	9.42	7.91	6.74	5.52	4.42					
MED	4.36	4.56	5.03	6.07	7.95	8.43	9.00	9.46	7.62	6.45	5.37	4.56					
MAX	6.09	5.75	5.65	6.69	8.41	8.97	9.89	11.52	9.13	8.61	7.80	4.97					
MIN	3.11	4.04	3.78	4.91	6.26	8.16	7.94	7.28	6.91	5.76	4.17	3.72					

MONTHLY PAN EVAPORATION DATA

REFERENCE: DLNR, 1973

DAMES & MOORE

TABLE 2.2

CHECKED BY ____ DATE ____ FILE ____ BY ____ DATE ____

BY ______ DATE ______

FILE ______ 113-56

CHECKED BY ______

Station No. 741 — EWA MILL

ISLAND OF OAHU

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1961	4.10	4.25	5.65	6.14	8.16	7.25	7.67	7.99	6.36	5.60	4.62	4.16	72.06	6.00	5.91	8.16	4.10
1962	4.06	4.06	5.17	6.39	6.99	8.47	9.94	8.90	8.02	6.11	6.01	3.63	77.79	6.48	6.25	9.94	3.63
1963	3.76	4.50	5.18	6.90	6.94	8.09	8.57	8.04	4.95	6.13	4.48	3.24	72.78	6.06	6.51	8.57	3.24
1964	4.05	5.36	4.91	5.93	7.82	8.23	8.44	4.14	7.39	6.21	4.73	4.73	76.16	6.34	6.07	8.44	4.05
1965	4.41	4.81	4.06	6.62	5.96	8.70	8.24	7.99	6.31	5.66	4.48	4.50	73.76	6.14	6.01	8.70	4.41
1966	4.49	3.81	5.92	6.35	7.43	9.32	10.03	9.29	6.98	5.47	3.81	4.10	77.00	6.41	6.13	10.03	3.81
1967	4.01	4.24	4.43	5.47	6.87	7.52	8.20	7.67	7.04	5.67	5.02	3.94	70.55	5.87	5.67	8.20	3.94
1968	3.75	4.27	5.01	6.10	7.19	8.56	9.46	9.68	7.12	5.65	4.77	3.66	75.22	6.26	5.87	9.68	3.66
1969	4.00	——	6.36	7.86	7.55	7.44	8.73	8.80	6.59	5.59	4.50	4.02	71.44	6.49	6.59	8.80	4.00
1970	3.69	4.89	5.47	7.39	8.58	8.85	9.31						49.18	7.02	7.39	9.31	3.69
TOTAL	40.34	40.26	55.41	65.35	73.69	82.43	88.81	76.52	62.76	52.17	42.42	35.98					
MEAN	4.03	4.47	5.54	6.53	7.36	8.24	8.83	8.50	6.97	5.79	4.71	3.99					
MED	4.03	4.28	5.41	6.37	7.31	8.35	8.68	8.14	6.98	5.67	4.62	4.02					
MAX	4.49	5.36	6.47	7.86	8.58	9.32	10.03	9.68	8.02	6.21	6.01	4.73					
MIN	3.69	3.81	4.68	5.67	5.96	7.25	7.67	7.67	6.31	5.47	3.81	3.24					

Station No. 751.2 — ROCK PILE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN	MED	MAX	MIN
1962										7.54	7.01	5.03	19.58	6.52	7.01	7.54	5.03
1963	5.68	4.66	5.45	6.68	6.79	7.97	8.74	8.14	7.39	6.45	5.35	3.76	77.04	6.42	6.56	8.74	3.76
1964	4.58	6.08	5.70	7.04	8.71	9.18	8.99	9.73	8.31	7.85	5.86	4.51	86.54	7.21	7.44	9.73	4.51
1965	4.91	6.56	7.28	6.81	6.36	9.97	9.59	10.17	7.75	6.69	5.07	4.84	85.96	7.16	6.75	10.17	4.84
1966	4.31	3.07	5.92	6.94	8.23	10.20	10.56	10.26	8.40	6.80	5.10	4.84	84.63	7.05	6.87	10.56	3.07
1967	4.93	5.74	5.18	6.30	7.06	8.41	9.13	8.33	8.02	6.80	6.59	5.30	81.79	6.81	6.69	9.13	4.93
1968	4.40	4.75	5.43	6.29	6.67	8.56	8.86	8.59	7.47	6.26	5.37	4.19	77.04	6.42	6.27	8.86	4.19
1969	5.00	4.71	——	7.79	8.10	7.96	8.90	9.31	7.47	6.34	5.37	5.23	76.18	6.92	7.47	9.31	4.71
1970	4.50	5.19	7.24	8.48	8.36	8.57	9.65						51.97	7.42	8.36	9.65	4.50
TOTAL	38.31	40.72	42.40	56.33	60.26	70.82	74.42	64.53	54.81	54.73	45.72	37.70					
MEAN	4.78	5.09	6.05	7.04	7.53	8.85	9.30	9.21	7.83	6.84	5.71	4.71					
MED	4.74	4.97	5.70	6.37	7.58	8.56	9.06	9.31	7.75	6.74	5.37	4.84					
MAX	5.68	6.56	7.28	8.48	8.71	10.20	10.56	10.26	8.40	7.85	7.01	5.30					
MIN	4.31	3.07	5.18	6.29	6.36	7.96	8.74	8.14	7.39	6.26	5.07	3.76					

MONTHLY PAN EVAPORATION DATA

REFERENCE: DLNR, 1973

DAMES & MOORE

TABLE 2.3

TABLE 3

WELL DATA

Dames & Moore Well No. Oahu Sugar Well No.	1 EP 23	2 EP 30	3 EP 21	4 EP 22	5 EP 20	6 EP 24	7 EP 27A,B 28 & 29
Year Drilled	1931	1965	1930	1930	1930	1932	1964
Casing Diameter (in)	12		12	12	12	12	
Ground Elevation (ft)	43	5	25	23	25	24	5
Total Depth (ft)	47	8	30	29	30	29	8
Bottom of Hole Elev. (ft)	-4	-3	-5	-6	-5	-5	-3
Pump Capacity (mgd)					2.9		
Draft (mgd)	4.8	0.5	0.7	1.8		0.1	5.1
Static Head (ft)		1.4		2.1	0.7	1.8	
Maximum Chloride (mg/l)	898	1300	937	660	600	625	760
Minimum Chloride (mg/l)	505	639	470	520	480	472	620

Reference: State of Hawaii
Dept. of Land & Natural Resources
Division of Water & Land Development
August 31, 1984

TABLE 4

SUMMARY OF TIDAL RESPONSE AND SALINITY PROFILE DATA VICINITY PROPOSED BARBERS POINT HARBOR

OBS. HOLE NO.	DIST. FROM COAST, FT.	MODIFIED DIST., FT.	DEPTH TO LENS (bk.pt.) FT. FRM. MSL.	GROUND ELEV. FROM MSL, FT.[2]	AMPLITUDE RATIO (a/a_o)[3]
36	435	240	14	5.3	.93
37	1005	400	25	11.0	.79
38	1395	800	30	7.2	.74
39	1785		36	10.2	.50
40	2535		--	11.9	.31
41	3120		40	6.6	.29
42	1500		28	9.5	.64
43	1380	600	19	4.0	.74
44	3210		38	16.0	.29
30	3000		--	9.4	.26

REFERENCE: Williams, 1976

TABLE 5

CHLORIDE DATA

Oahu Sugar Wells

Dames & Moore Well No.	Oahu Sugar Well No.	DLNR/USGS Well No.	1958-1970[1] (mg/l)	1976-1980[2] (mg/l)	1986[3] (mg/l)
1	23				1100
2	30	1900-13	640-1300		1020
3	21	2000-01	480- 610		930
4	22	1900-02	590- 670		830
5	20	1900-01	470- 590		920
6	24	1901-01	440- 590		940
7	27A&B, 28, 29	1902-01	620- 840	585-800	870

[1] Reference: Swain (1973)

[2] Reference: Board of Water Supply (1983)

[3] Dames & Moore Test Data (1986)

TABLE 6

NITRATE DATA (NO_3 - N)

Dames & Moore Well Number	Oahu Sugar Well Number	1986 Dames & Moore NO_3 - N	1985 Oahu Sugar NO_3 - N	1985 * CH_2M Hill NO_3 - N
1	23	9.26	2.8	
2	30	7.68	2.5	
3	21	7.45	2.6	
4	22	7.77	2.2	
5	20	6.10	2.4	
6	24	6.10	1.6	
7	27A&B,28,29	5.87	2.0	2.99

* State of Hawaii Dept. of Land & Natural Resources, Report R-74, August 1985.

TABLE 7

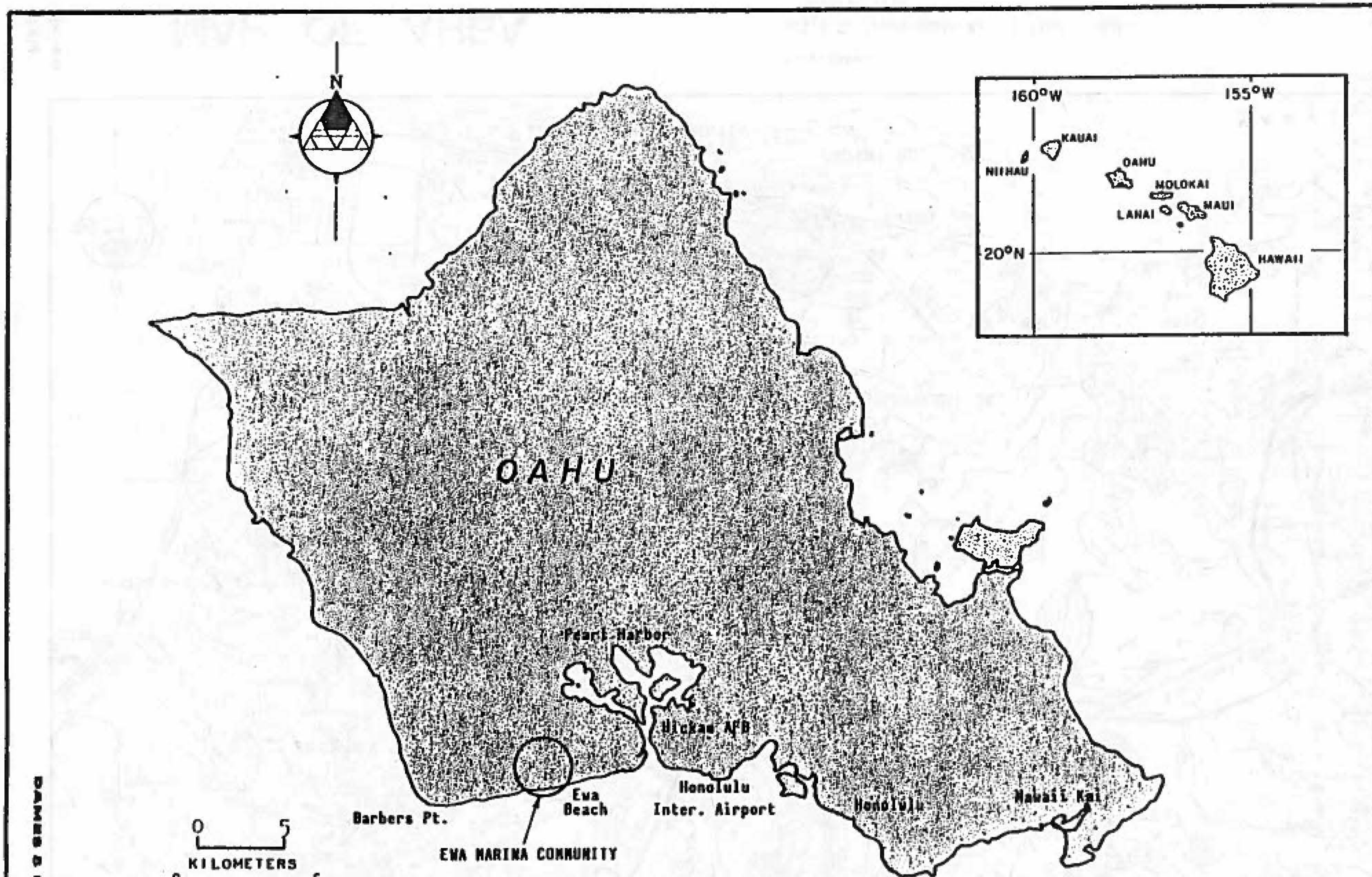
COMPUTER MODELING RESULTS

LOCATION	COORDINATES	APPROXIMATE CHANGE IN POTENTIAL HEAD (H1-H2) (D1) (FT)	(H1-H3) (D2) (FT)	(H1-H4) (D3) (FT)	PERCENTAGE CHANGE IN POTENTIAL HEAD D2/D1 (%)	(D3-D1)/D3 (%)
WELL 1	(35,19)	0.35208	0.04959	0.35788	14.08487	1.62065
WELL 2	(38,14)	0.21417	0.05903	0.22217	27.56222	3.60085
WELL 3	(36,15)	0.31784	0.08779	0.32984	27.62082	3.63813
WELL 4	(36,12)	0.25190	0.09204	0.26450	36.53831	4.76371
WELL 5	(35,15)	0.34980	0.10144	0.36380	28.99943	3.84827
WELL 6	(32,14)	0.40398	0.16590	0.42819	41.06639	5.65403
WELL 7	(21,10)	0.31650	0.11990	0.29360	37.88310	-7.79973
OP-1	(15,18)	0.79100	0.04900	0.78900	6.19469	-0.25349
OP-2	(20,20)	0.94500	0.06500	0.94700	6.87831	0.21119
OP-3	(29,23)	0.57000	0.02600	0.57140	4.56140	0.24501
OP-4	(31,18)	0.53060	0.09690	0.54198	18.26234	2.09971
OP-5	(34,9)	0.19134	0.10653	0.20739	55.67576	7.73904

LEGEND:

H1 - PRE-DRIP IRRIGATION AND PRE-MARINA INSTALLATION
H2 - POST-DRIP IRRIGATION AND PRE-MARINA INSTALLATION
H3 - PRE-DRIP IRRIGATION AND POST-MARINA INSTALLATION
H4 - POST-DRIP IRRIGATION AND POST-MARINA INSTALLATION
D1 = H1-H2
D2 = H1-H3
D3 = H1-H4

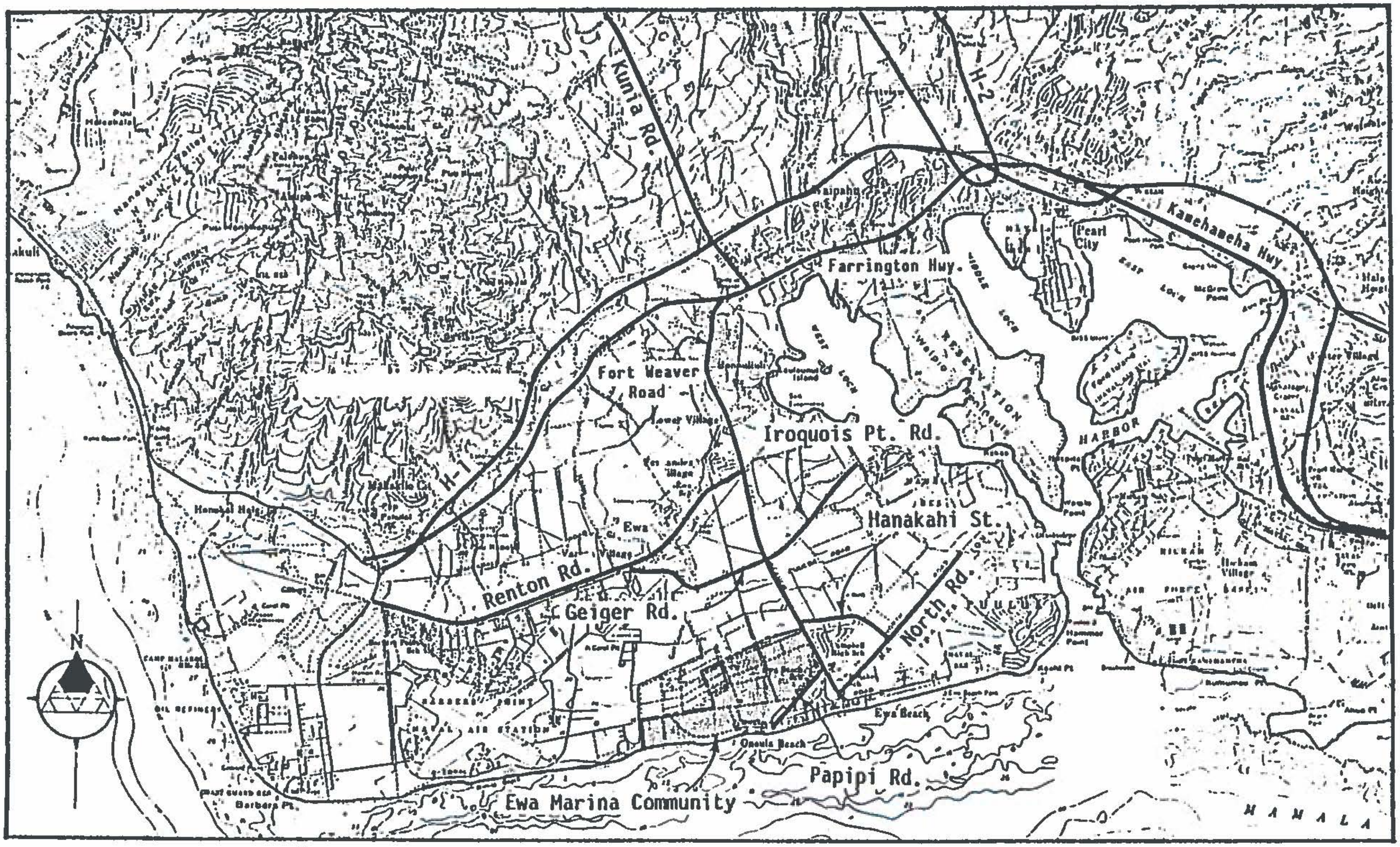
BY ______ DATE ______ CHECKED BY ______ FILE ______ REVISIONS BY ______ DATE ______



VICINITY MAP
PROPOSED EWA MARINA COMMUNITY

DAMES & MOORE

1



MAP OF AREA

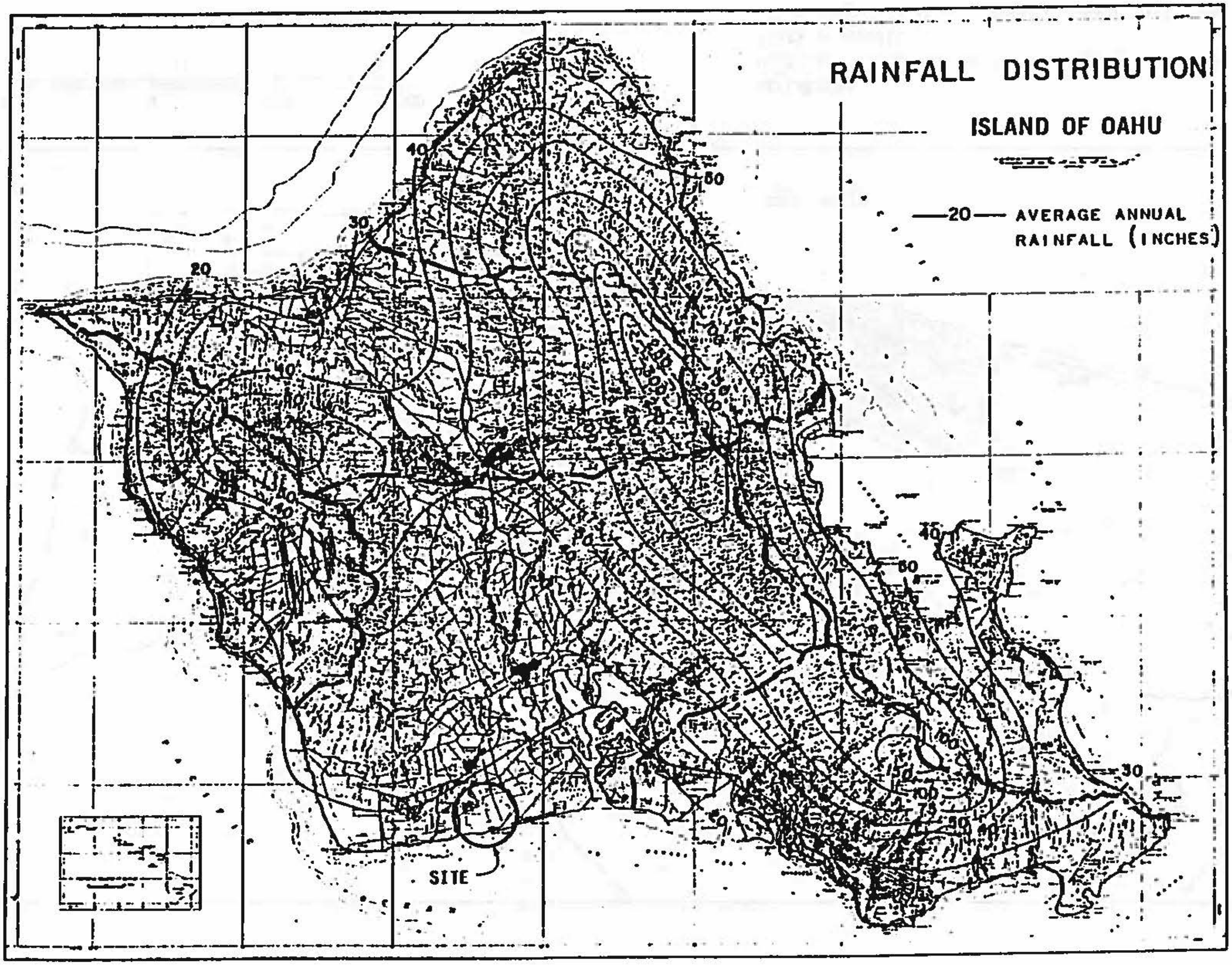
5000 0 5000 10 000
FEET

Reference:

U.S.G.S. Topographic Map, Island of Oahu
Dated 1954.
Group Architects Collabortive, Inc.
E.M.C. Generic EIS
February 1982

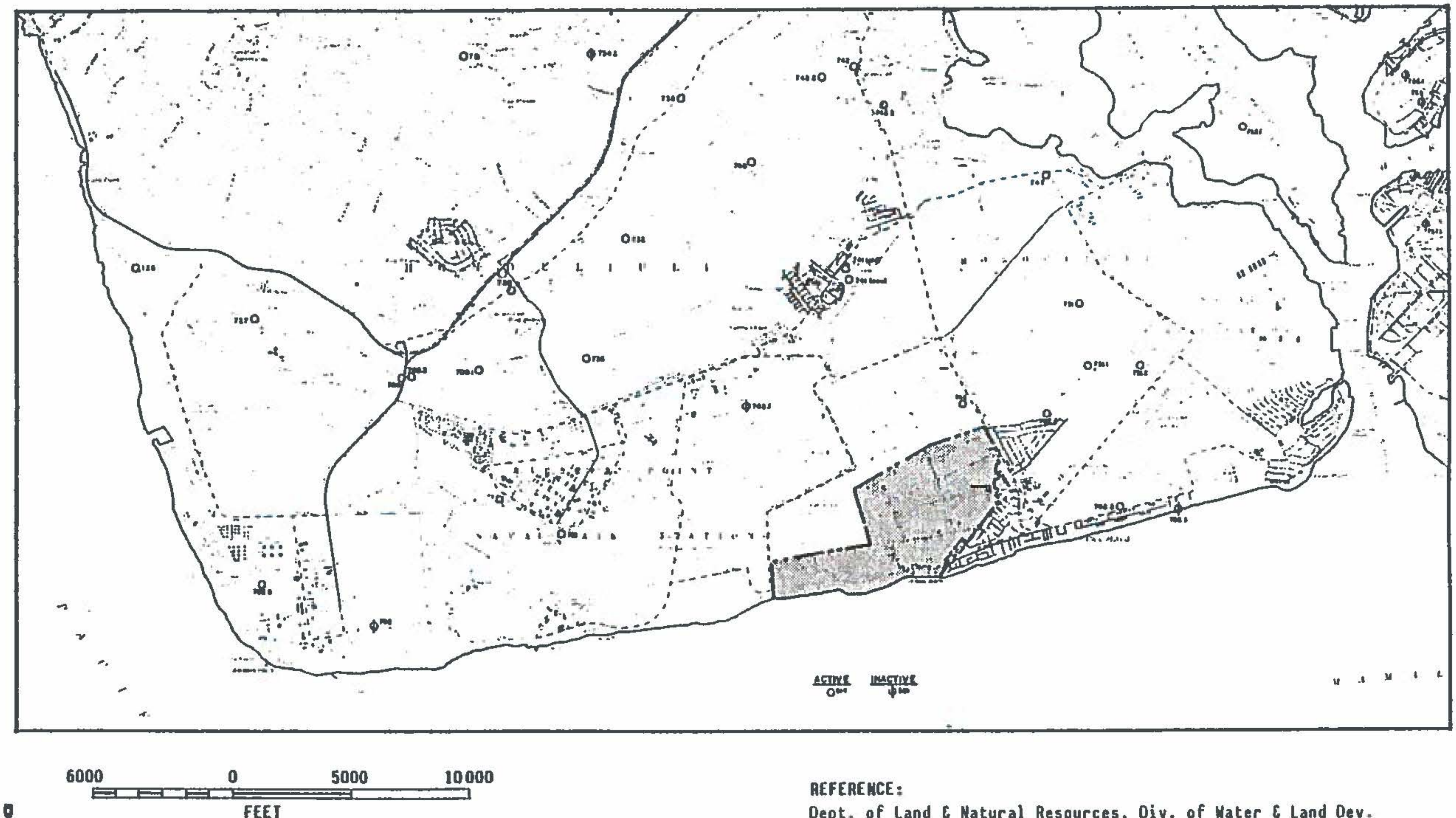
DAMES & MOORE
PLATE 2

CHECKED BY ________ FILE 00113-563 ________ BY ________ DATE ________



REFERENCE: DEPARTMENT OF LAND AND NATURAL RESOURCES, STATE OF HAWAII
REPORT R42, 1973

DAMES & MOORE
PLATE 3



RAINFALL GAUGE LOCATIONS

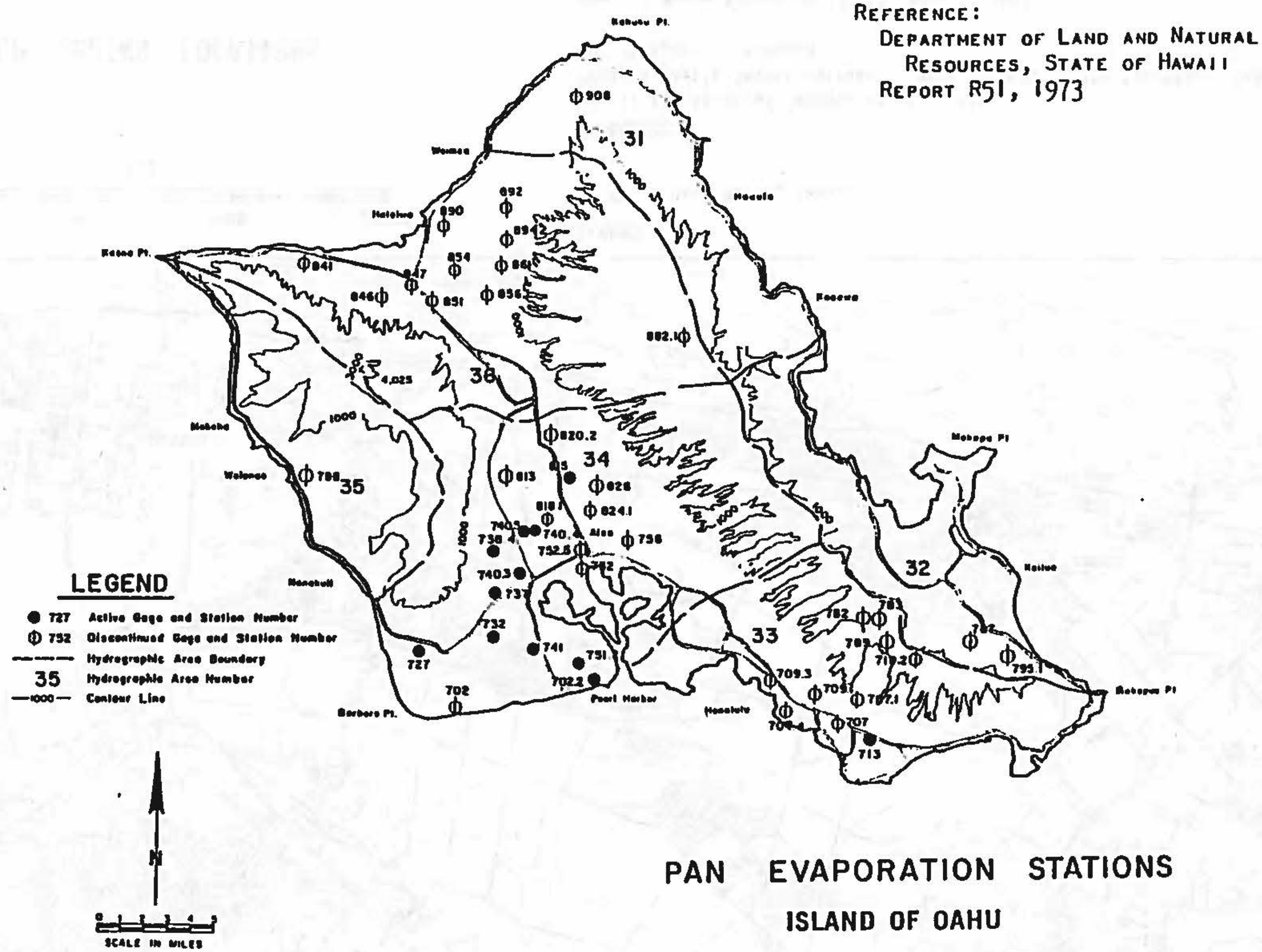
REFERENCE:
Dept. of Land & Natural Resources, Div. of Water & Land Dev.
State of Hawaii
Climatologic Station in Hawaii, Report R42, Jan. 1973
Quads: 0-06 & 0-10, p.p. 33 & 37

DAMES & MOORE

PLATE 4

CHECKED BY ______________ FILE ______________________________ BY ________ DATE ______

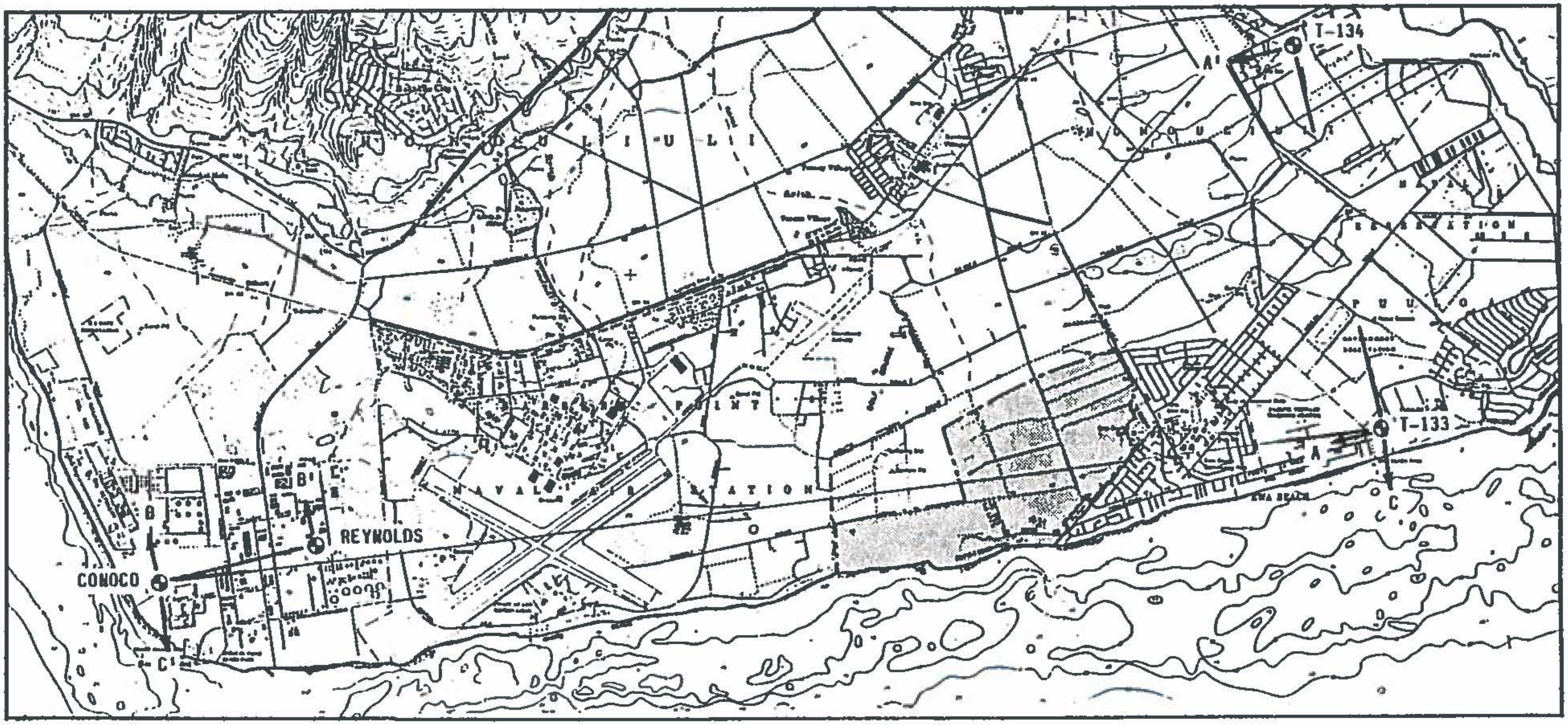
REFERENCE:
DEPARTMENT OF LAND AND NATURAL RESOURCES, STATE OF HAWAII
REPORT R51, 1973



PAN EVAPORATION STATIONS

ISLAND OF OAHU

DAMES & MOORE
PLATE 5



5000 0 5000 10000

FEET

LEGEND:

Deep Boring Location

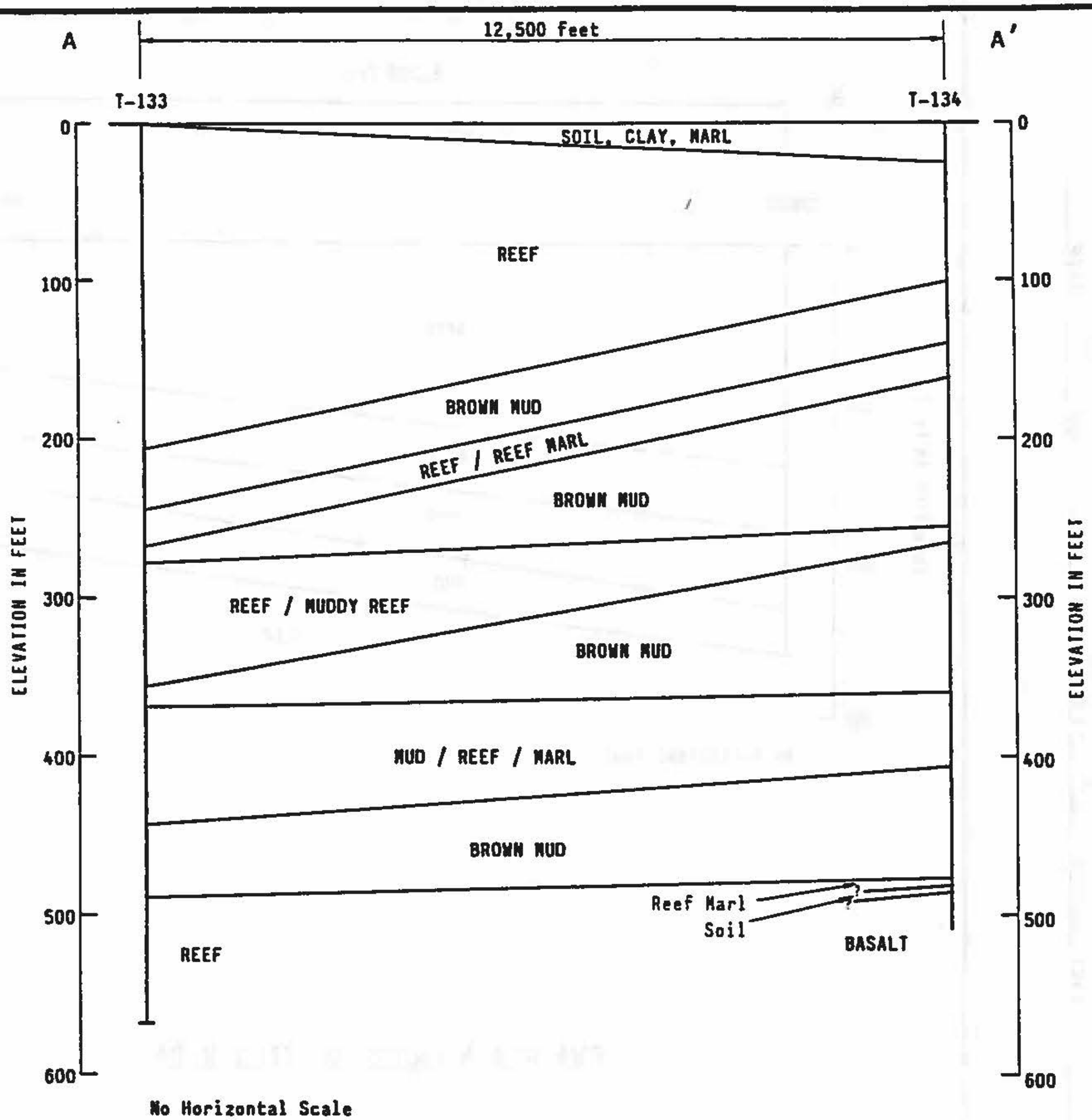
DEEP BORING LOCATIONS

REFERENCE:
Hawaii Institute of Geophysics, May 1970
"Paleomagnetic Investigations of Deep Borings on the Ewa Plain, Oahu, Hawaii"
By: Stephen R. Hammond

Dames & Moore Report 00113-563, May 27, 1981

DAMES & MOORE

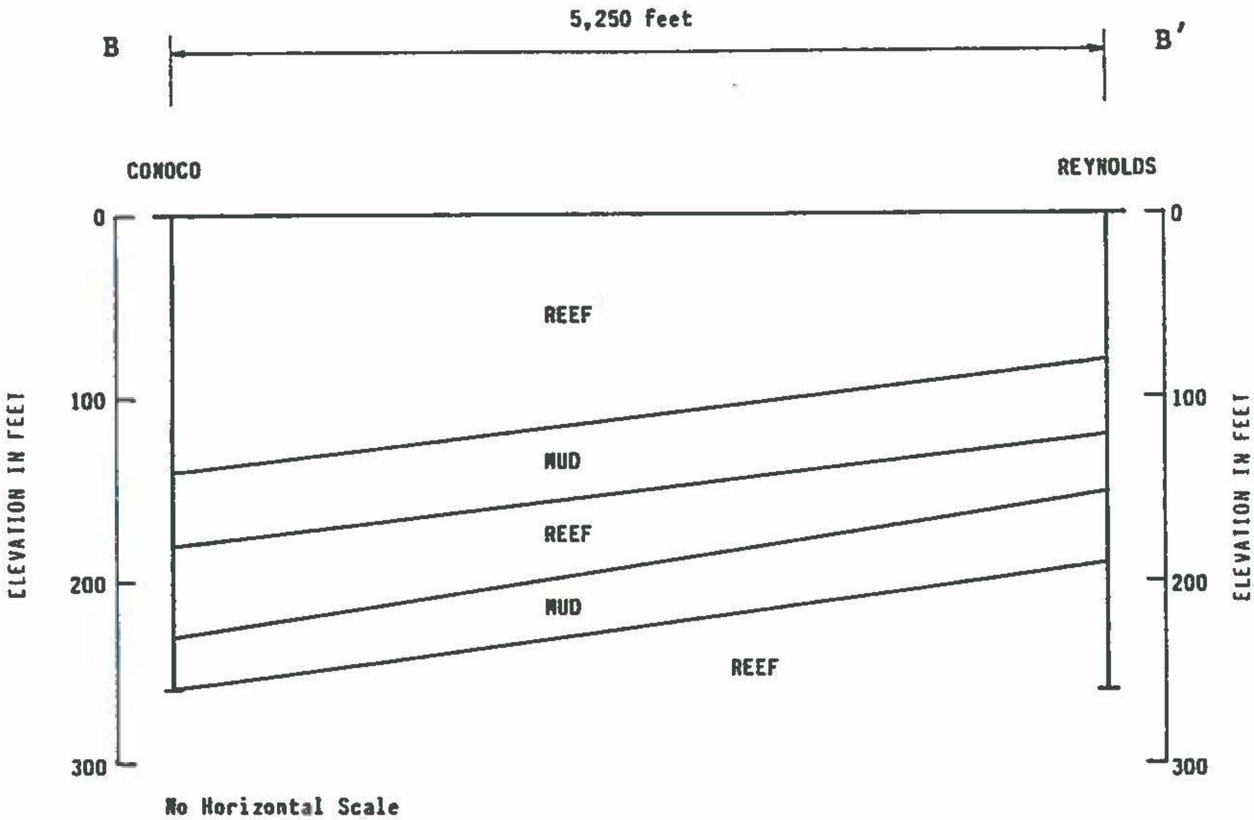
PLATE 6



EWA PLAIN CROSS SECTION A-A'

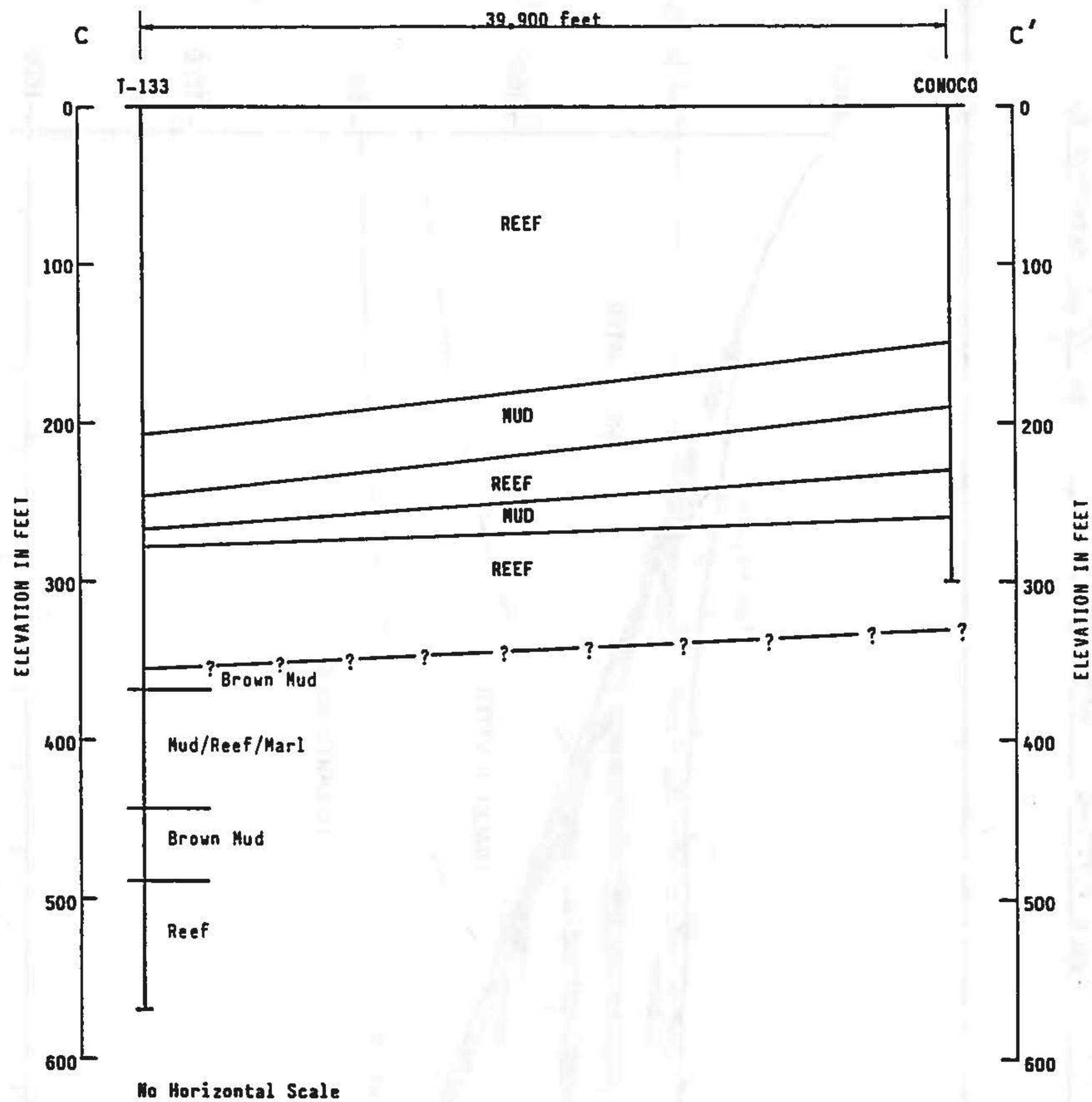
DAMES & MOORE
PLATE 7.1

REVISIONS BY DATE
FILE
CHECKED BY DATE



EWA PLAIN CROSS SECTION B-B'

DAMES & MOORE
PLATE 7.2

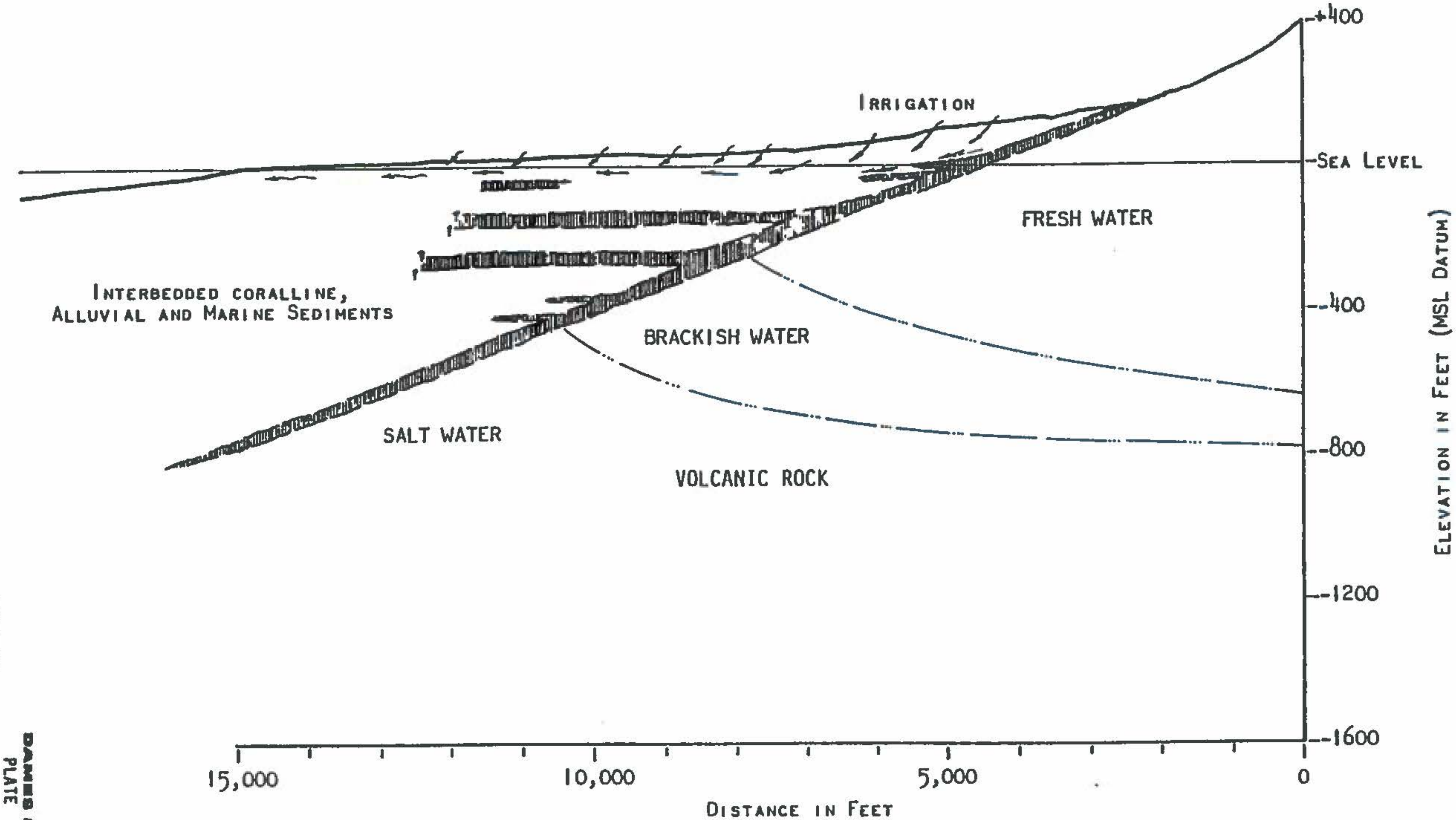


EWA PLAIN CROSS SECTION C-C'

DAMES & MOORE
PLATE 7.3

REVISIONS BY ___ DATE ___
FILE ___
BY ___ DATE ___
CHECKED BY ___

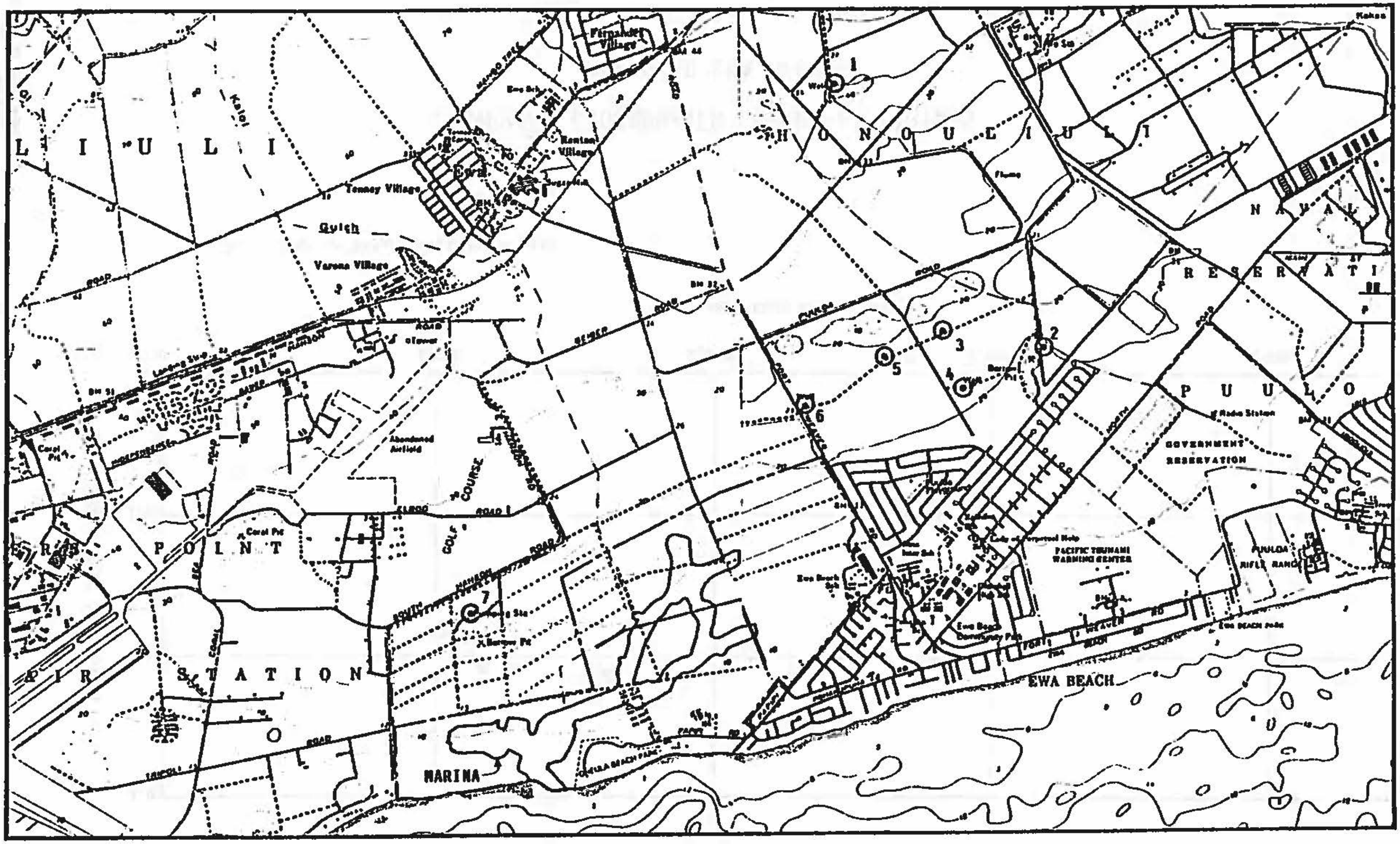
BY ____ DATE ____
CHECKED BY ____
FILE 113-563
REVISIONS
BY ____ DATE 4-16-81



DAMES & MOORE
PLATE 8

GENERALIZED GEOLOGIC CROSS-SECTION OF EWA PLAIN

REFERENCE: BOARD OF WATER SUPPLY, 1963



EXISTING WELL LOCATIONS

3000 0 1000 2000
FEET

LEGEND:

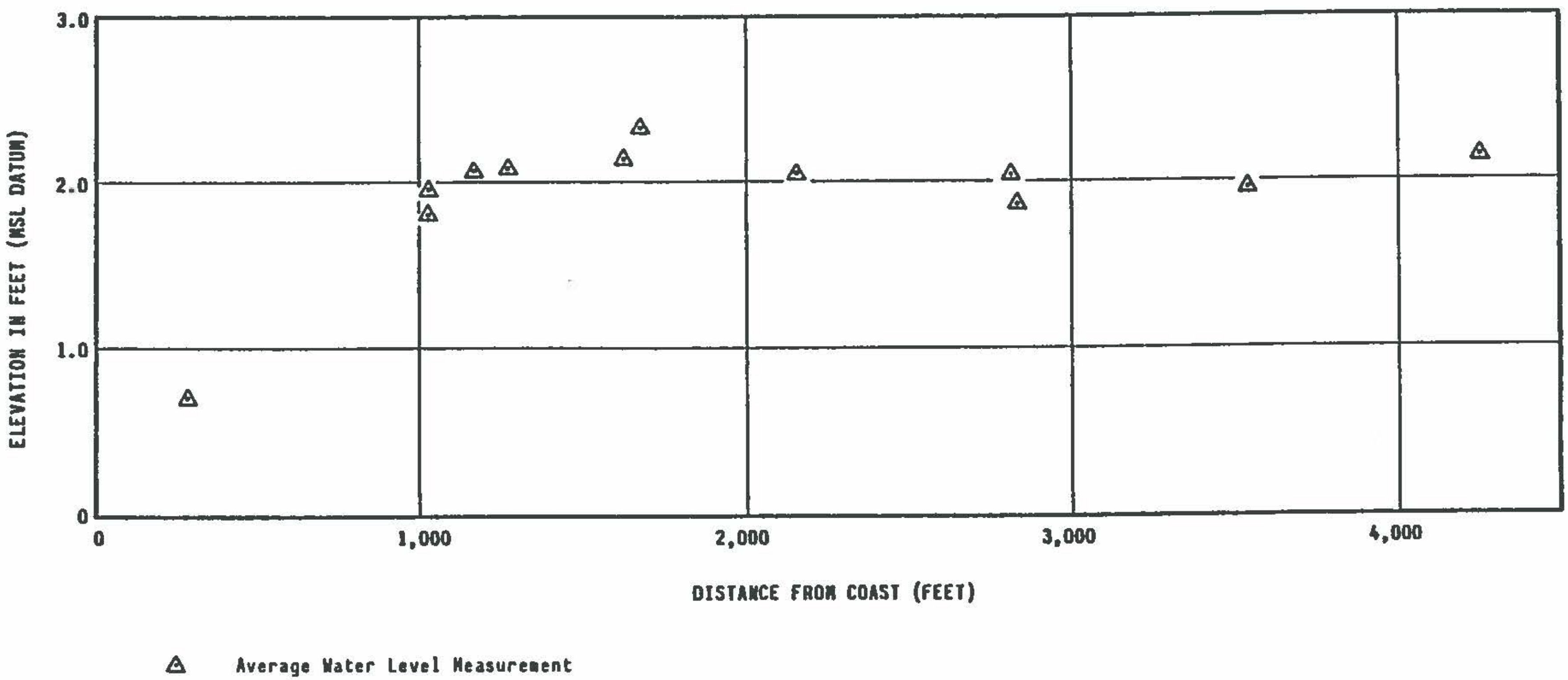
⊙ Well Sites

REFERENCE:
Department of Land & Natural Resources, Div. Water & Land Dev.
State of Hawaii, 1972

DAMES & MOORE

PLATE 9

BY ____ DATE ____ CHECKED BY ____ FILE ____ REVISIONS BY ____ DATE ____



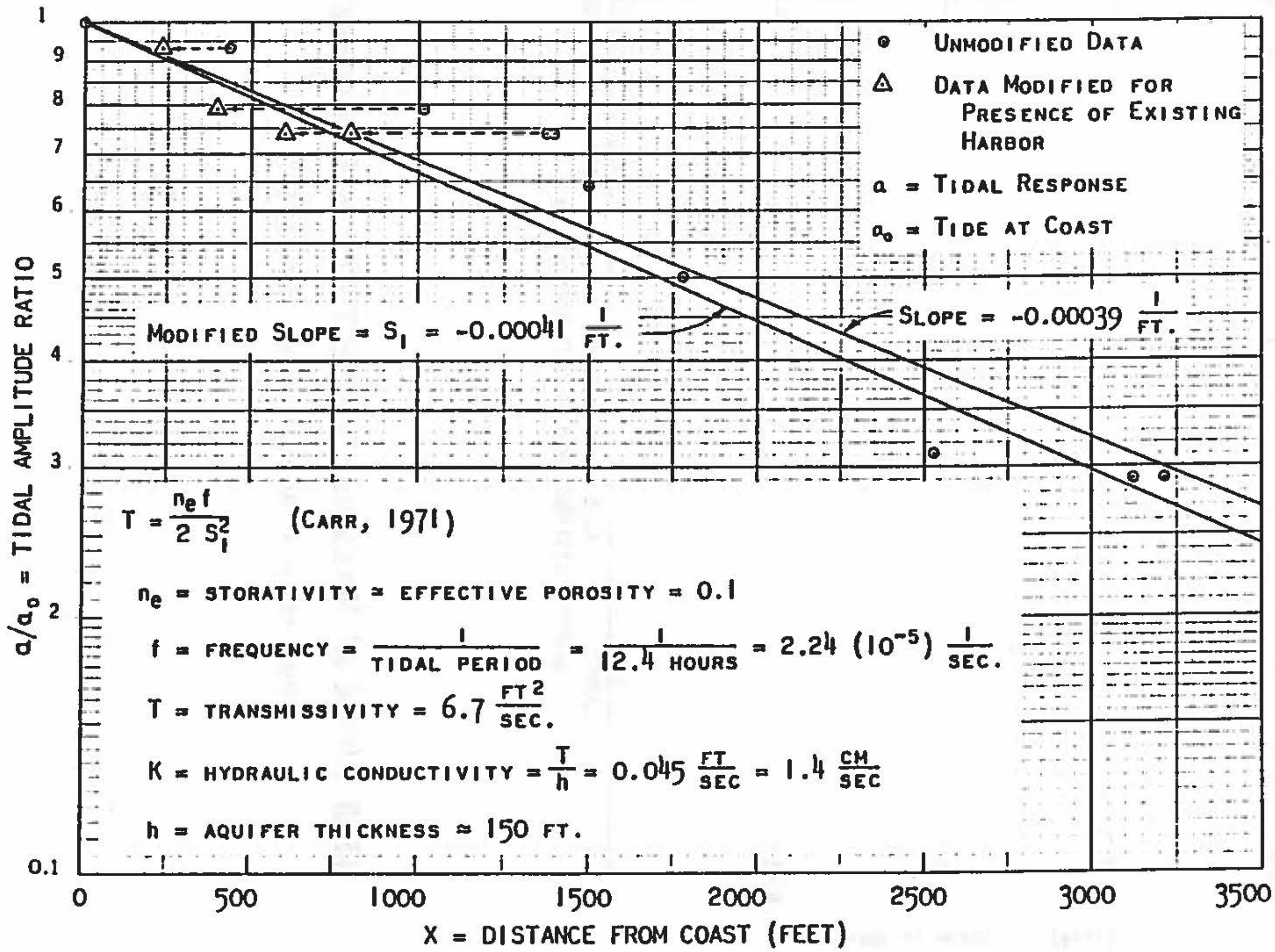
AVERAGE GROUNDWATER LEVELS AT BORINGS

PROPOSED EWA MARINA

DAMES & MOORE

PLATE 10

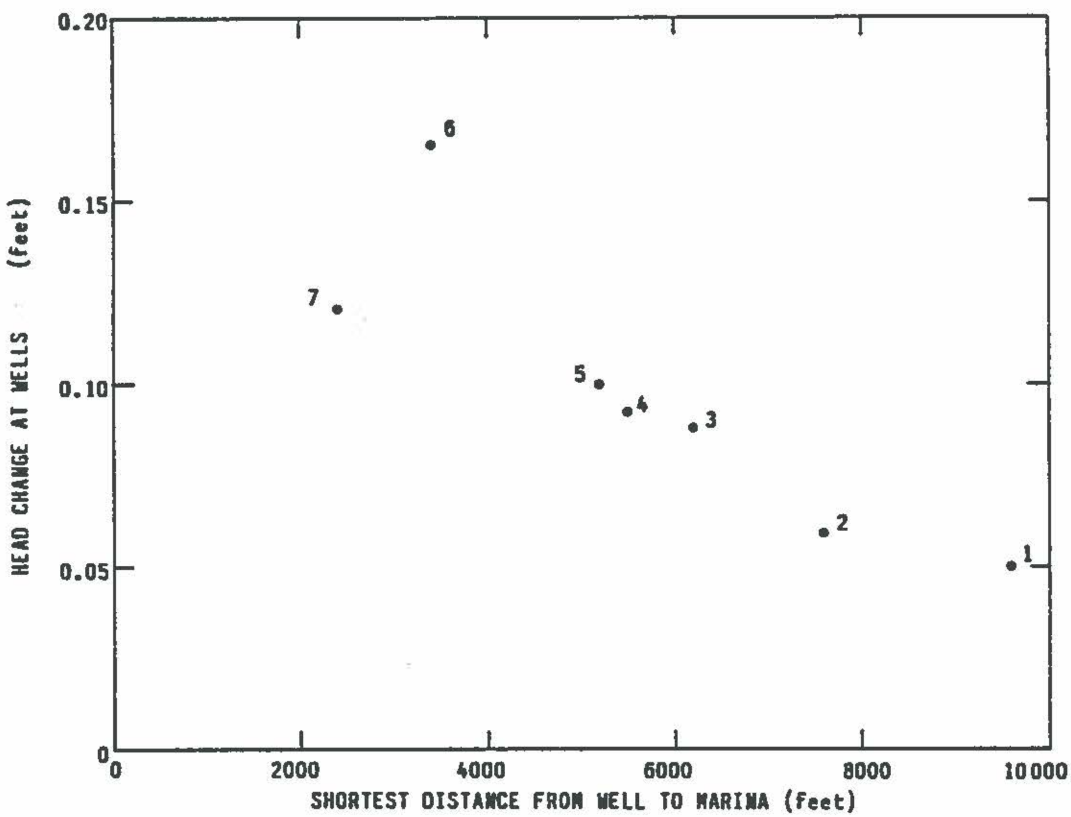
CHECKED BY ________ FILE 0112-563 ________ BY ________ DATE ________



TIDAL AMPLITUDE RATIO VS. DISTANCE FROM THE COAST

REFERENCE: DATA BY U.S. ARMY CORPS OF ENGINEERS (WILLIAMS, 1976)

DAMES & MOORE
PLATE 11



HEAD CHANGE AT WELLS vs. SHORTEST DISTANCE FROM MARINA

PRE-DRIP / POST-MARINA CONDITION

REVISIONS BY ____ DATE ____

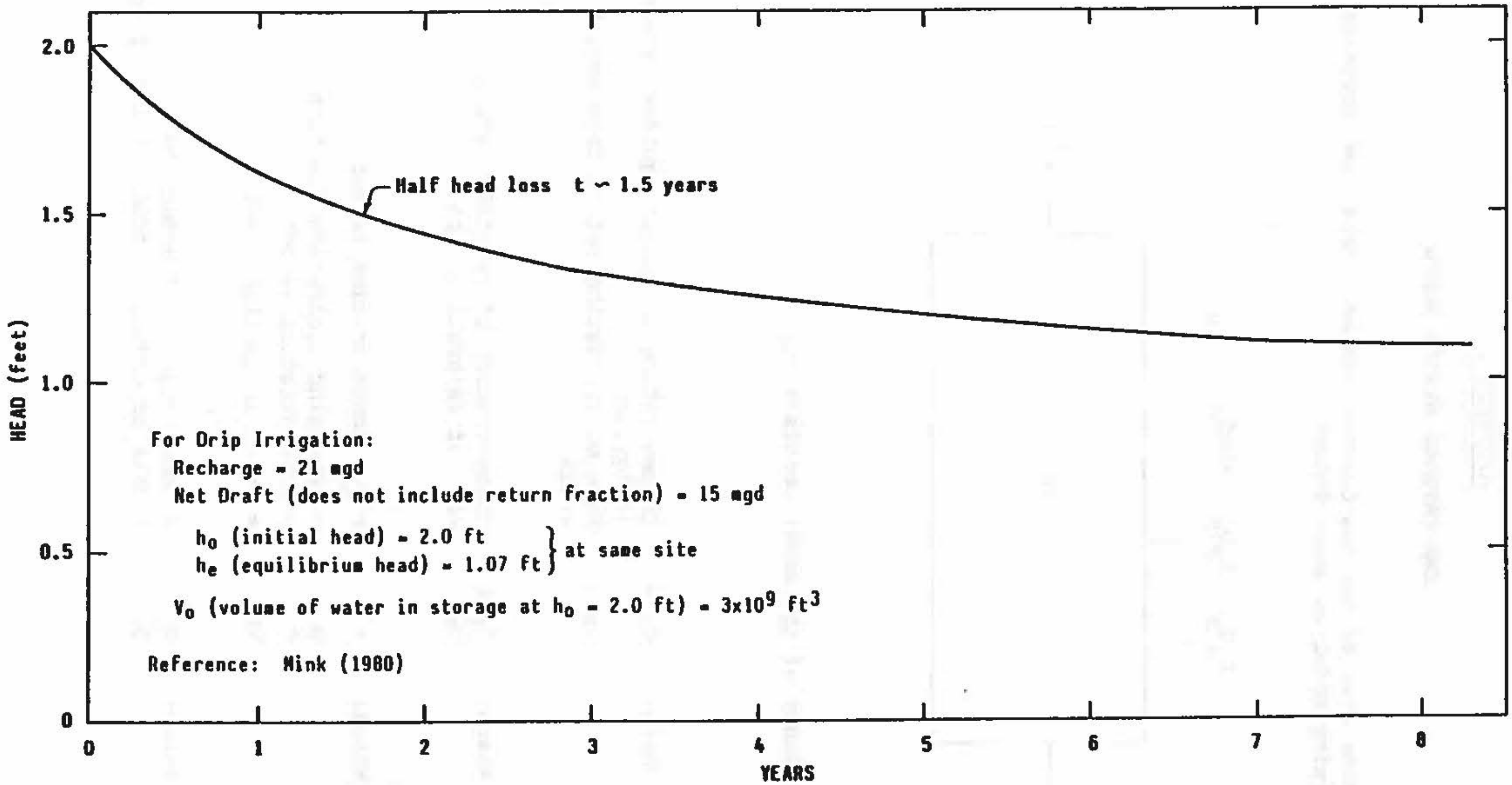
FILE ____

BY ____ DATE ____

CHECKED BY ____

946.7 (REV. 6-61)

BY ______ DATE ______
CHECKED BY ______
FILE 13822.002
REVISIONS
BY ______ DATE ______



DECAY IN HEAD AS A RESULT OF THE CHANGE TO DRIP IRRIGATION

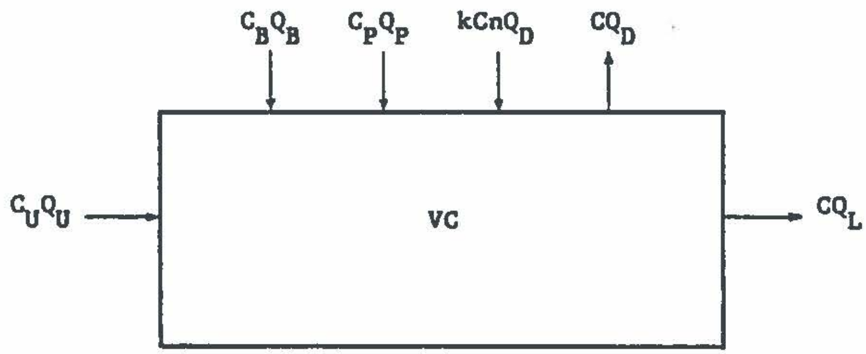
CAPROCK AQUIFER

DAMES & MOORE
PLATE 13

APPENDIX A

EWA CAPROCK MIXING MODEL

The limestone area of the Ewa Caprock can be generalized graphically by a single cell mixing model as shown below:



The mass balance of the model consists of:

A. INPUT

1. C_BQ_B

   Where:
   - C_B = Concentration of basalt aquifer return irrigation
   - Q_B = Rate of irrigation return from basalt aquifer wells

2. C_PQ_P

   Where:
   - C_P = Concentration of rainfall return
   - Q_P = Rate of rainfall return

3. $kCnQ_D$

   Where:
   - k $= \frac{1}{n}$ = Concentration factor
   - n = Returning irrigation fraction
   - C = Concentration in cell
   - Q_D = Total irrigation draft

4. C_UQ_U

   Where:
   - C_U = Concentration of underflow
   - Q_U = Rate of underflow from outside of model

(2891A/277A)

B. <u>WITHIN CELL</u>

1. VC

Where: V = Volume of cell
C = Concentration of mixing cell
C_0 = Concentration of mixing cell at time = 0

C. <u>OUTPUT</u>

1. CQ_D

Where: C = Concentration of mixing cell
Q_D = Total irrigation draft

2. CQ_L

Where: C = Concentration of mixing cell
Q_L = Leakage from system

Which can be written as:

$$Q_L = Q_{INPUT} - Q_D$$

Where: $Q_{INPUT} = Q_U + Q_B + Q_P + nQ_D$

Substituting: $Q_L = Q_U + Q_B + Q_P + nQ_D - Q_D$

Or: $Q_L = Q_U + Q_B + Q_P - (1-n)Q_D$

For the mixing cell, the following equation can be written for the mass balance:

$$V(dC) = \sum C_iQ_i \Big|_{INPUT}(dt) - \sum C_iQ_i \Big|_{OUTPUT}(dt)$$

By letting: $a = C_BQ_B + C_PQ_P + C_UQ_U$
$b = (1-n)Q_D - Q_B - Q_P - Q_U$

Then the equation can be rewritten as:

$$\int_{C_o}^{C} \frac{dC}{a+bC} = \frac{1}{V}\int_{o}^{t} dt$$

Integrating and solving for C yields:

$$C = \frac{a+bC_o}{b}\left(e^{bt/v}\right) - \frac{a}{b} \quad \text{(Transient equation)}$$

Solving for steady state condition where time approaches infinity:

$$e^{bt/v} \longrightarrow 0 \quad \text{(because b is a negative value)}$$

Therefore:

$$C = -\frac{a}{b}$$

Substituting for a and b:

$$C = -\frac{C_B Q_B + C_P Q_P + C_U Q_U}{(1-n)Q_D - Q_B - Q_P - Q_U}$$

Solving for Q_U:

$$Q_U = \frac{C_B Q_B + C_P Q_P + C[(1-n)Q_D - Q_B - Q_P]}{C - C_U}$$

The boundaries and conditions of the limestone aquifer include:

A.	Cane Land over limestone	=	4,414 acres
B.	Non-cane land over limestone	=	9,024 acres
C.	Total area	=	13,438 acres = 21 sq. miles
D.	Mean annual rainfall for area	=	22 inches/year
	For total area,		
	Total precipitation (TP)	=	(22 inches/year)(21 sq. miles)
		=	22 million gallons per day (Mgd)

Using the above information, the following scenarios were investigated.

Scenario 1

Assume Q_P and Q_B are the only inputs to the mixing cell (Q_U=0). Find the value of C at steady state.

Using precipitation recharge percentage of 27.3 percent:

Q_P = (0.273)(TP) = (0.273)(22 Mgd)

Q_P = 6 Mgd

C_P = 0 (Actually C_P 0, however, C_P very small)

Based on furrow irrigation of 4,400 acres requires 44 Mgd of water and the caprock wells can only supply 24 Mgd, implies that 20 Mgd is supplied by the basalt aquifer wells. Using n = 0.5:

Q_B = 0.5 (20 Mgd) = 10 Mgd

C_B = 800

Total irrigation draft from caprock:

Q_D = 24 Mgd

Substituting in following equation:

$$C = -\frac{C_B Q_B + C_P Q_P + C_U Q_U}{(1-n)Q_D - Q_B - Q_P - Q_U}$$

$$C = -\frac{(800)(10Mgd) + (0)(6Mgd) + C_U(0)}{(1-0.5)(24Mgd) - (10Mgd) - (6Mgd) - 0}$$

$C =$ 2,030 milligrams per liter (mg/l) Cl^-

The actual chloride level is approximately 800 mg/l. Therefore, it can be concluded that there must be underflow into the mixing cell. However, it should be noted that the model assumes no sea water mixing occurs in the limestone.

(2891A/277A)

Scenario 2

Solve for Q_U, assuming the following:

C	$= 800$	Q_P	$= 6$ Mgd
C_U	$= 500$	Q_B	$= 10$ Mgd
C_B	$= 800$	Q_D	$= 24$ Mgd
C_P	$= 0$	n	$= 0.5$

Substituting in the following equation:

$$Q_U = \frac{C_B Q_B + C_P Q_P + C[(1-n)Q_D - Q_B - Q_P]}{C - C_U}$$

$$Q_U = \frac{800(10\text{Mgd}) + 0(6\text{Mgd}) + 800[(1-0.5)(24\text{Mgd}) - (10\text{Mgd}) - (6\text{Mgd})]}{800 - 500}$$

$$Q_U = 16 \text{ Mgd}$$

Of this 16 Mgd, assign 12 Mgd from return irrigation flow on 2,425 acres overlying alluvium between termini of limestone and the sea level isopoch of the basalt. This leaves 4 Mgd as leakage directly into the limestone from the basalt. It can then be seen that:

A. Present System

Q_{INPUT}:

$Q_U = 16$ Mgd

$Q_B = 10$ Mgd

$Q_P = 6$ Mgd

Total $= 32$ Mgd

Q_{OUTPUT}:

$nQ_D = 12$ Mgd

Total $= 12$ Mgd

Flow through system $= Q_{INPUT} - Q_{OUTPUT}$
$= 20$ Mgd

B. Undeveloped State

Q_{INPUT}:

$Q_U = 4$ Mgd

$Q_B = 0$

$Q_P = 6$ Mgd

Total $= 10$ Mgd

Flow through system $= 10$ Mgd

Scenario 3

Restrict area of model to Puuloa limestone area where all fields are irrigated by caprock wells. Assume the following:

A. Area cane land = 4.32 square miles
B. Area of non-cane land = 4.1 square miles
C. Total area = 8.42 square miles
D. Mean annual rainfall for area = 22 inches/year
For this area, total precipitation (TP) = 22 inches/year (8.42 square miles) = 8.82 Mgd
E. Recharge percentage of 25 percent for precipitation
F. $Q_B = 0$, $Q_D = 22$ Mgd
G. $C = 800$, $C_U = 500$, $C_B = 800$, $C_P = 0$, and $n = 0.5$

Then:

$$Q_P = (0.25)(TP) = 0.25(8.82 \text{ Mgd})$$

$$Q_P = 2.2 \text{ Mgd}$$

Substituting in the following equation:

$$Q_U = \frac{C_B Q_B + C_P Q_P + C[(1-n)Q_D - Q_B - Q_P]}{C - C_U}$$

$$Q_U = \frac{800(0) + 0(2.2\text{Mgd}) + 800[(1-0.5)(22\text{Mgd}) - 0 - 2.2\text{Mgd}}{800 - 500}$$

$$Q_U = 23.5 \text{ Mgd}$$

This value includes return irrigation from inland fields and underflow.

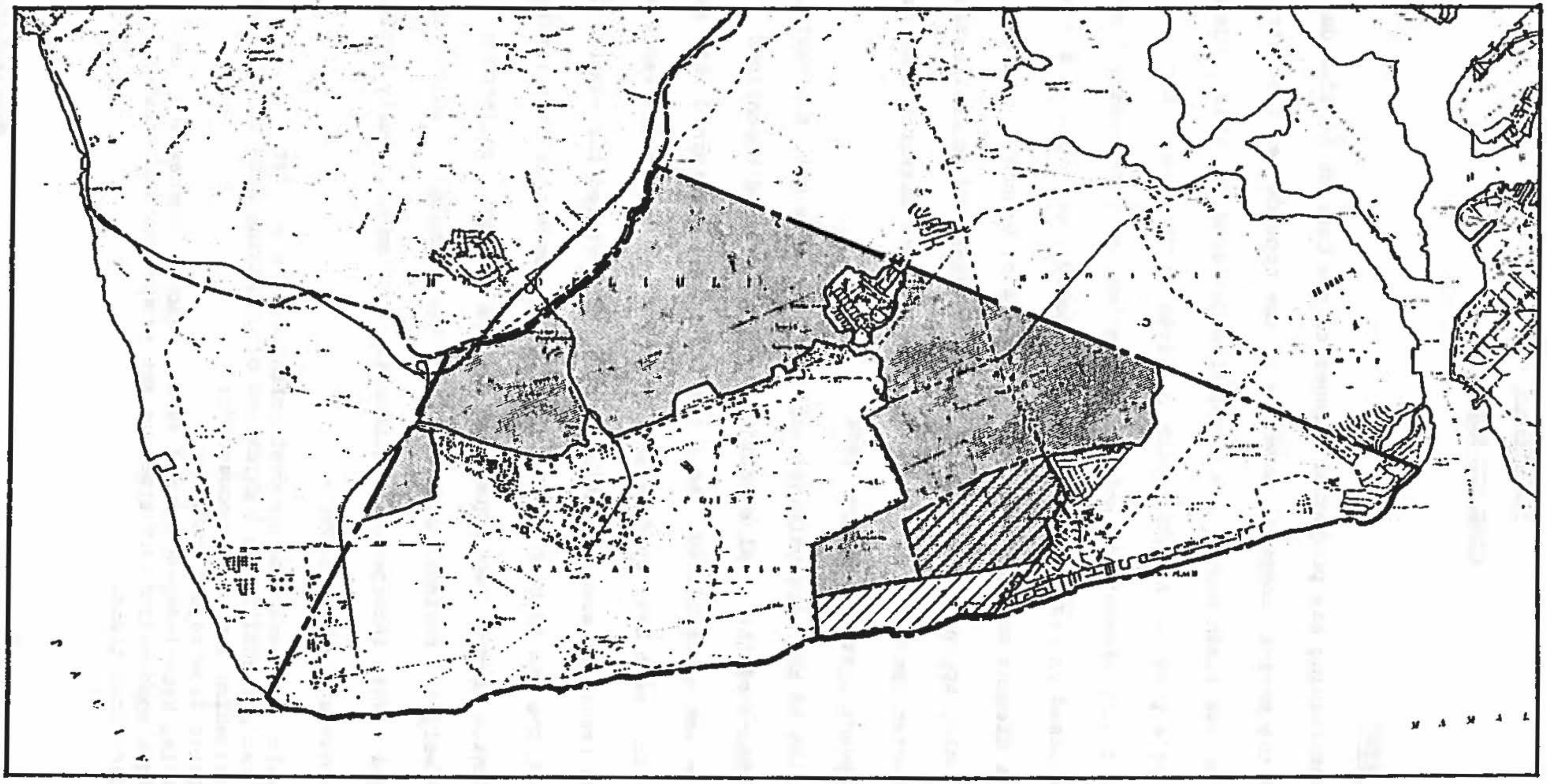
APPENDIX B

COMPUTATION OF THE GROUNDWATER FLUX

The rate ground-water flow toward the ocean was calculated using a mass balance approach. An area of the Ewa Plain representing the flow system in the vicinity of the proposed Ewa Marina Community was isolated as shown in Plate B-1. Total recharge in this area was calculated as a sum of rainfall and infiltration due to irrigation. For a conservative calculation, it was assumed that there were no other water sources or sinks in the vicinity, thus resulting in a groundwater flux equivalent to the recharge. The calculations are summarized below:

R_T = $R_P + R_I$
R_T = Total Recharge
R_P = Recharge due to precipitation
= Annual rainfall x percent rainfall reaching ground water
= (22 in/yr) x (0.25)
= 0.5 ft/yr
= (0.5 ft/yr) x (total acreage)
= (0.5 ft/yr) x (11,783.9 acres)
= 5891.95 acre-ft/yr
R_I = Recharge due to irrigation
= Irrigation - Evapotranspiration
= 3.5 ft/yr (Dale 1967)
= 3.5 ft/yr x (irrigated acreage)
= 3.5 ft/yr x (4,739.74 acres)
= 16,589.09 acre-ft/yr
R_T = 16,589.09 + 5,891.95
= 22,481.04 acre-ft/yr
= 20,069,779 gallons/day
Flux = R_T/length of shoreline
= (20,069,779 gpd)/(48,048 ft)
= 418 gpd/ft

(2904A/277A)



6000 0 5000 10000

FEET

LEGEND:

Boundary of study area

Contact between coastal plain deposit and basalt aquifer

Irrigated area

Ewa marina community project area

STUDY AREA FOR GROUND-WATER FLOW CALCULATIONS

REFERENCE:
U. S. Geological Survey, 1967; By: R.H. Dale
Land Use and Its Effect on Basal Water Supply,
Pearl Harbor Area, Oahu, Hawaii, 1931-65

DAMES & MOORE
PLATE B-1

APPENDIX C

COMPUTER MODELING

DESCRIPTION OF MODEL

To aid in determining the projected changes to the Caprock Aquifer due to installation of the marina, computer modeling of the groundwater flow was performed for the Ewa Plain area. The computer model used for this project was Dames & Moore's program, EP 110, which utilizes techniques of finite differences and finite elements to solve the equations of groundwater flow. This program is based on research by Richard C. Cooley documented in a report entitled "Finite Element Solutions for the Equations of Ground Water Flow". The report by Cooley appeared in Technical Report Series H-W as Publication No. 18 of the Center for Water Resources Research, Desert Research Institute, University of Nevada System, January, 1974.

By integration of the three-dimensional flow equations over the vertical, rigorous development of the areal equations for confined and unconfined groundwater flow was accomplished. As a result, it was determined that all of the areal equations were best written in terms of mean head in the vertical direction. The resultant areal equations can be descretized for numerical solution through the use of both a finite difference-numerical integration method and a finite element technique based on the subdomain collection variant of the weighted residual method. These two techniques, which were shown to be equivalent, incorporate continuously or discontinuously variable hydraulic parameters which include:

1. Transmissivity and storage coefficient of the aquifer;
2. Vertical permeability and thickness of confining beds or other units through which leakage is occurring;
3. Irregular flow region geometry;
4. Variable, head-independent and head-dependent sources and sinks;
5. Multiple combinations of time variant known-flow and known-head boundary conditions.

The matrix equations generated by the discretization techniques can be solved by various methods. The EP 110 program utilizes Stone's strongly implicit procedure as the matrix solution. This method, that was derived by H. L. Stone in 1968, is an approximate factorization technique.

APPLICATION OF MODEL

The Dames & Moore EP 110 computer program was employed using a finite element grid that approximated the caprock aquifer area in the Ewa Plain as shown on the Plot Plan, Plate C-1. To the east, south, and west, the boundary of the aquifer is the ocean shoreline. In the computer model, the ocean shoreline was simulated as a constant head boundary with a constant head potential of 0.0 feet. To the north, the aquifer boundary was taken as the contact between the coastal plain deposits and basaltic aquifer as shown on a map entitled "Land Use and Its Effects on the Basal Water Supply, Pearl Harbor Area, Oahu, Hawaii 1931-65", prepared by R. H. Dale (1967). From Appendix A, it has been approximated that the recharge of the caprock aquifer from the basaltic aquifer is about 4 million gallons per day (mgd). For the pre-drip condition, an additional 12 mgd of return flow results from irrigation of the overlying alluvium between the termini of the limestone and the sea level isopach of the basalt. For the post drip condition, this return flow is reduced to 6 mgd. For the model, this contact line was simulated by a known-flow boundary using a flow rate of 16 mgd distributed equally along the line for the pre-drip case and 12 mgd for the post-drip case.

An average aquifer transmissivity (T=Kh) of 400,000 ft^3/day/ft was used for the entire site. This transmissivity value represents an aquifer hydraulic conductivity (K) of 5,000 ft^3/day/ft^2 and a constant saturated thickness (h) of 80 feet.

The average precipitation rate over the modeled area is approximately 22 inches per year. For our model, we have estimated that the recharge of the caprock aquifer due to precipitation is approximately 27.3 percent of the annual rate or a value of 0.0014 feet per day applied over the entire area.

In addition to precipitation, the caprock aquifer is recharged from infiltration of irrigation water in excess of the amount required by the plans. The majority of the irrigated land in the modeled area is used for the cultivation of sugar cane by Oahu Sugar Company. For the model, irrigation recharge was applied to zones which approximated the area presently used for sugar cane cultivation based on information supplied to us by Oahu Sugar Company. It is our understanding that furrow irrigation was predominantly used prior to 1978 and drip irrigation after 1978. Based on available data, it was estimated that the irrigation recharge rate was 0.0096 feet per day for furrow irrigation and 0.0048 feet per day for drip irrigation.

Within the project area, there are seven wells presently in use. In the model, the wells were simulated by applying areal discharge in the zones adjacent to the well locations. The estimated discharge rates used for the well zones are as follows, based on 1984 pumping rates (Mink, 1986):

Wells		Discharge (million gallons per day)
1		8.2
2		0.8
3		1.4
4		0.7
5		0.8
6		1.0
7		6.3
	Total	19.2

To determine the overall long-term effects of the marina installation on the caprock aquifer, the computer model was solved for steady-state solutions. Further, due to the relatively recent change from furrow to drip irrigation which substantially reduced the recharge of the caprock aquifer, the effects of the change to drip irrigation was investigated first prior to the marina installation. In all, the following four cases were investigated:

1. Pre-drip irrigation and pre-marina installation
2. Post-drip irrigation and pre-marina installation
3. Pre-drip irrigation and post-marina installation
4. Post-drip irrigation and post-marina installation

The primary limitation of the applied model is that the initial assumed saturated thickness of the lens does not change as the heads change. Model results are therefore less valid in areas where head changes significantly, such as, immediately adjacent to the marina or the shoreline. However, the effects are much less in locations away from these areas, such as the vicinity of the Oahu Sugar wells. The model was primarily applied to assess the changes which would occur at the wells. For these areas, the model results can be considered a reasonable quantitative estimate of the net head changes.

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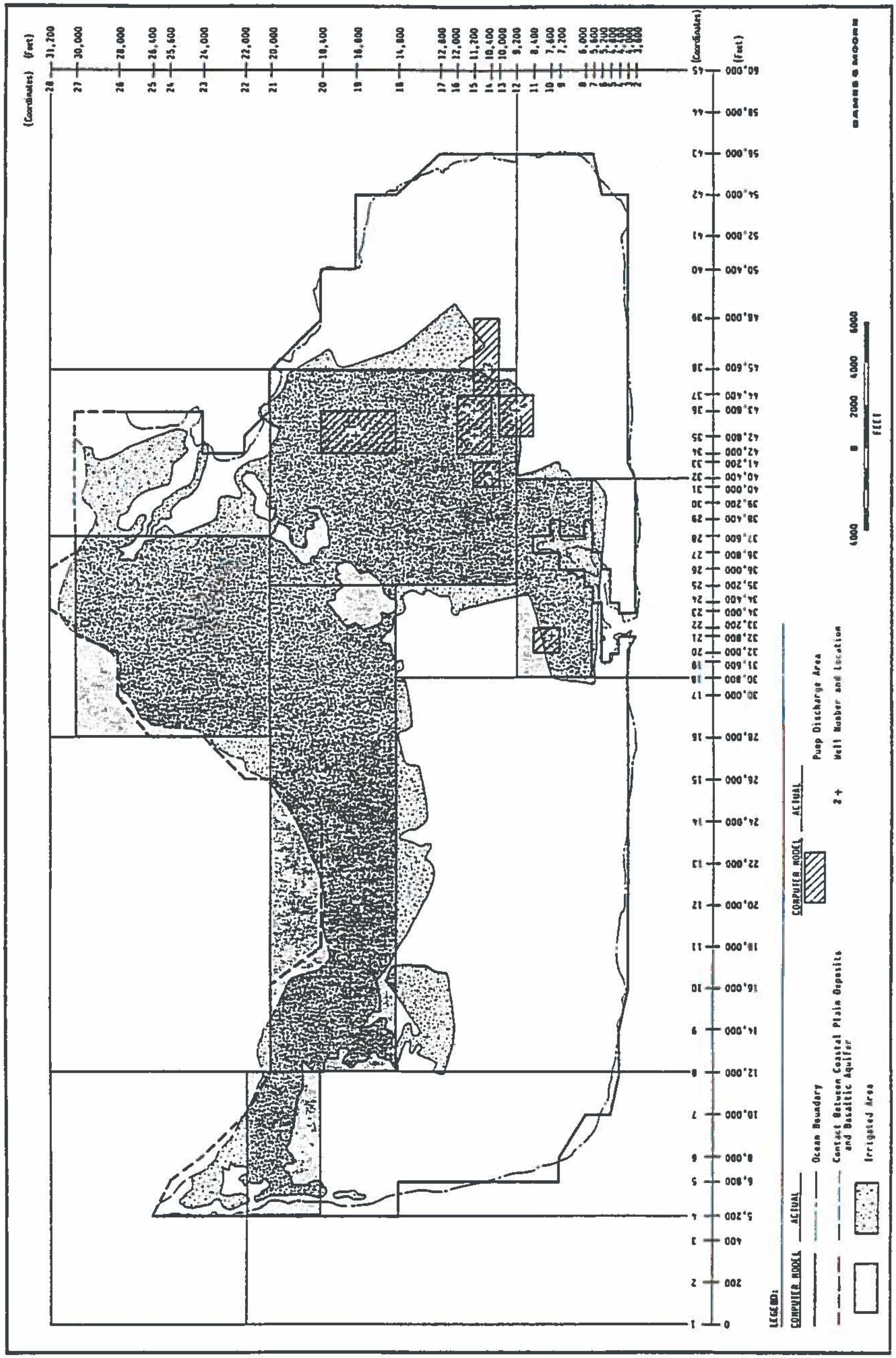
LEGEND:
COMPUTER MODEL
ACTUAL
Ocean Boundary
Contact Between Coastal Plain Deposits and Basaltic Aquifer
Irrigated Area
Pump Discharge Area
Well Number and Location
FEET
(Coordinates)
(Feet)
DAMES & MOORE

PLATE C-1

APPENDIX 7

TRAFFIC STUDY

APPENDIX 7

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TRAFFIC STUDY

FOR THE

EWA MARINA COMMUNITY

March, 1986

Prepared for

MSM & Associates, Inc.

Prepared by

KAKU ASSOCIATES
1427 Santa Monica Mall, #201
Santa Monica, CA 90401
(213) 458-9916

SUMMARY AND CONCLUSIONS

This document provides a summary of the results of a traffic study conducted for the Ewa Marina Community, a residential development planned for the Ewa District of Oahu. The project calls for the development of 4,850 dwelling units and about 55 acres of commercial development in Phase I, and the potential for an additional 2,350 dwelling units in Phase II. The study consists of three elements. They are:

* Assessment of the potential impact of Increment 1 of Phase I of the project which consists of 1,290 dwelling units on 160 acres of the 1000-acre project site.
* Traffic impact of the entire Phase I development and a cursory review of the impact of Phase II.
* Development of a master plan of streets and roads internal to the site based on Phase I levels of development.

The following is a summary of the results of the traffic assessment conducted for Increment 1.

* Increment 1 of the project is expected to generate 7,870 daily vehicle trips into and out of the site. Of these, 665 vehicles per hour are expected to occur during the morning peak hour, and 875 vph during the evening peak hour.
* Of the trips generated by Increment 1 of the project, 85 percent are expected to travel to and from destinations located north of the site and 15 percent south of it.
* By the completion of Increment 1, the traffic on Fort Weaver Road is expected to increase by about 20 percent as a result of regional growth and development and other specific projects planned for the area. The addition of the Ewa Marina Increment 1 traffic would increase the volume on Fort Weaver Road by an additional 15 percent.

* If Fort Weaver Road is widened to four lanes to Hanakahi Road as is currently planned by the State of Hawaii D.O.T. (construction cntracts have been let for the constructin project), the highway and all its intersections would operate at a very high level of service (LOS C or better) after the completion of Increment 1 of the Ewa Marina Community.

* When Fort Weaver Road is widened to four lanes to Hanakahi Street, the four-lane roadway will extend south past Road A, the northernmost access point in the site. Single lanes into and out of both access roads, Roads A and B, will be sufficient to accommodate the Increment 1 traffic. Road B is planned for completion during Year 1 with Road A planned for Year 2 or 3 of Increment 1.

The following summarizes the results of the analysis for Phases I and II.

* At the conclusion of Phase I, the Ewa Marina would generate approximately 40,000 daily trips, 2,400 vehicles per hour during the morning peak hour, and 3,700 vehicle trips per hour during the evening peak hour.

* The Phase I development is expected to generate 2,200 vehicles per hour external to the site during the morning peak hour and 2,500 vph during the evening peak hour.

* The traffic generated by Phase I would increase the traffic on Fort Weaver Road and other existing or planned facilities by amounts varying from 15 to 55 percent. The other projects in the area are also expected to add to the total traffic volumes on these facilities.

* When the planned widening to Fort Weaver Road is completed, the total projected traffic after the completion of Phase I of Ewa Marina and the other projects in the area would cause several intersections to operate at LOS E. However, all the locations are expected to function at LOS E or better during both the morning and evening peak hours.

* It would be necessary to have double left-turn lanes out of the project site at both access points on Fort Weaver Road, with separate left-turn and right-turn lanes on Fort Weaver Road itself for southbound traffic and left-turn lanes for northbound traffic at these two intersections. It will also be necessary to provide left-turn storage lanes at Renton Road, Geiger Road, and Papipi Road.

* Phase II of the project is expected to increase the external traffic to 3,200 vph during the morning peak hour and 3,800 vph during the evening peak hour.

* The addition of the Phase II traffic would require the addition of a second north-south road parallel to Fort Weaver Road. This road is expected to divert 35 to 45 percent of the Ewa Marina traffic from Fort Weaver Road.

The following summarizes the conclusions regarding the on-site master plan of streets and roads.

* The traffic generated by Phase I would require four lanes on Road A to accommodate the future traffic levels. Road B could be designed as a two-lane roadway if left-turn lanes are provided at the access points into and out of the various parcels. The left-turn lanes will not be needed initially but will be added in the future as warranted as traffic levels on Road B increase.

* All of the other roadways on the site would be able to accommodate Phase I levels of traffic with a two-lane width.

* It is recommended that signals be provided at three locations: the intersection of Roads A and B with Fort Weaver Road, and the intersection of Road A and Road C. It does not appear that any other additional locations will need signalization.

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I. INTRODUCTION

MSM & Associates, Inc., proposes to develop a 1,000-acre parcel of land in the Ewa District on the Island of Oahu. The planned project is a residential development built around a proposed marina with retail and specialty commercial in support of residential units. As part of the overall planning process for the proposed project, several traffic studies have been conducted to evaluate the potential impact of the future traffic on the planned street and highway system. This report documents the results of a traffic study conducted to combine and summarize data from previous efforts including the following:

* A Traffic Analysis for the Ewa Marina Community, PRC Voorhees, October, 1980.
* A Traffic Study for the Ewa Marina Community, Supplement for Phase I, Increment 1, Kaku Associates, February, 1984.

These previously conducted studies provided the majority of the base data which was supplemented with more recent information from the State of Hawaii Department of Transportation and the City and County of Honolulu Department of Transportation Services. The scope of this current study is broader than the previous efforts and includes the following elements:

* Evaluation of the potential impact of traffic from Increment 1 of Phase I of the project on the street system.
* Evaluation of the potential impact of traffic generated by Phase I as a whole on the street system.
* A general overview of the potential impact of Phase II traffic on the street system.

* The development of the master plan of internal roadways for the project including traffic control device requirements at key intersections.

This analysis attempted to assess the potential impact of the proposed Ewa Marina Community on the street system within the context of appropriate levels of future traffic and future highway improvements. For the first element of the study (Increment 1 only), the analysis considered the impact for future conditions both with and without the proposed widening of Fort Weaver Road from Renton Road to Hanakahi Street. For the second element, all of Phase I, the analysis assumed that the entire widening project for Fort Weaver Road would be completed. The completion of the second north/south access road was assumed for the assessment of Phase II impacts.

The following sections contain a description of the existing conditions as they relate to the transportation system; the projected future conditions in terms of land use and transportation improvements; an assessment of potential future impacts as a result of the completion of Increment 1, all of Phase I, and Phase II; and the roadway requirements for the project in terms of a Phase I master plan.

II. EXISTING CONDITIONS

The project site is isolated from major urban communities and is currently situated on agricultural (sugar cane) land. The Barbers Point Naval air station abutts the western boundary of the site, while the Ewa Beach community and the Pearl Harbor Naval Reservation at Iroquois Point surround the site on the east. Forming the southeast boundary of the site is a small housing community. Areas north of the project site are agricultural land except for the small community of Ewa New Town.

HIGHWAY FACILITIES

The key highway facility which serves the site is Fort Weaver Road, a state highway which provides direct access to Interstate H-1 and Farrington Highway, two highways of regional significance. Fort Weaver Road has a full interchange with H-1 and a newly constructed interchange with Farrington Highway. It has also been recently widened and realigned from Farrington Highway to Renton Road, north of the site. It is a major two-lane undivided rural arterial from Renton Road to Papipi Road, south of the site. It is the only facility providing access from Ewa Beach, Iroquois Point, and the project site to Waipahu, central Honolulu, Leeward Oahu, and Central Oahu. Access to Fort Weaver Road from the sugar cane fields and residential communities is currently provided by numerous plantation and minor county collector roadways. Traffic signals along Fort Weaver Road are provided at intersections with Papipi, Iroquois and Renton Roads. The H-1 freeway is a major facility with three lanes in each direction at the vicinity of the Kunia interchange. The major roadways providing access are also shown in Figure 1.

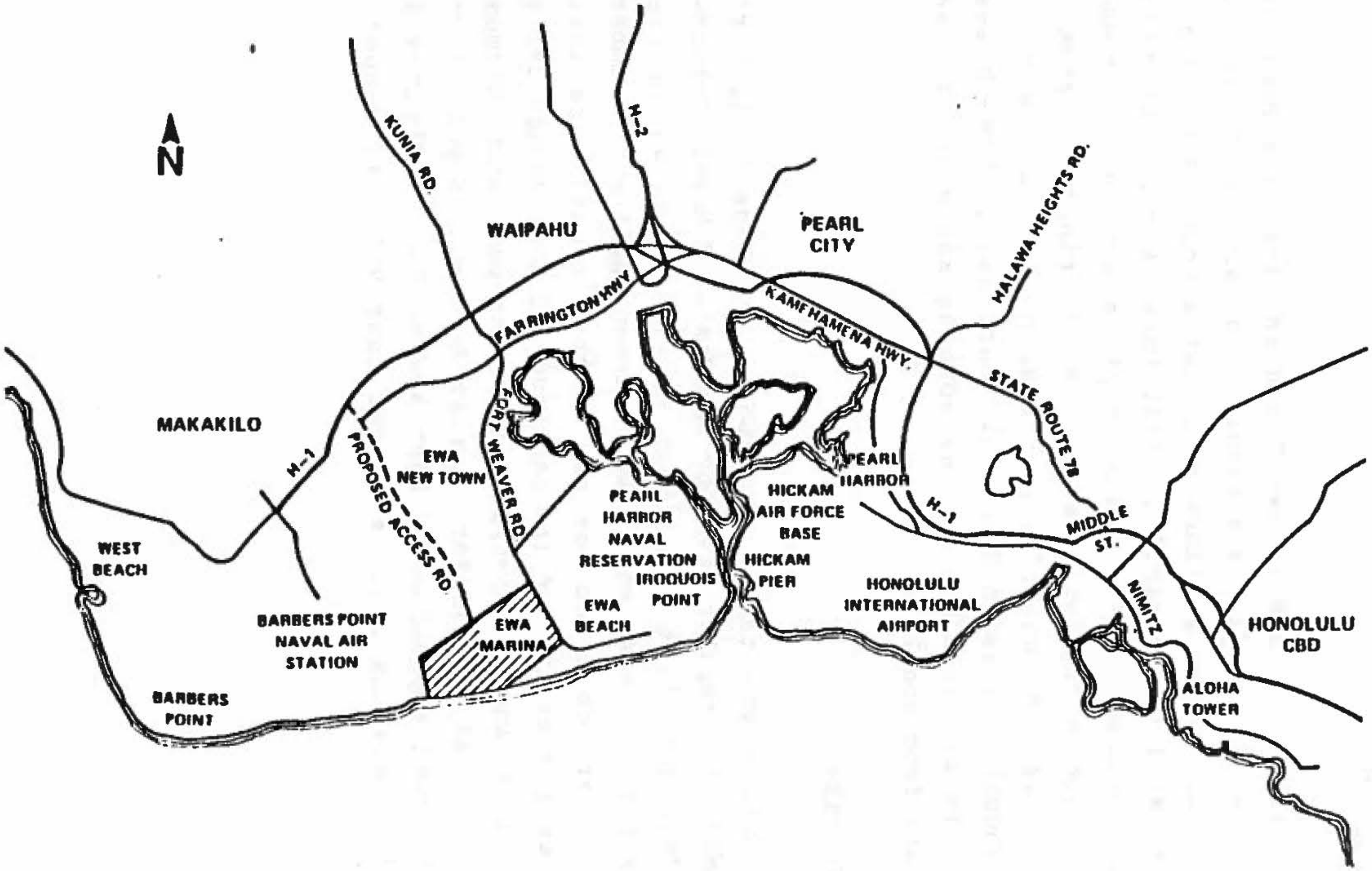

Figure 1

PROJECT SITE LOCATION

TRANSIT SERVICE

Current transit service to Ewa Beach and Iroquois Point is being provided by the City and County of Honolulu by Route 50. This route has three sublines which serve Iroquois Point/Ewa Beach, Ewa Mill and Makakilo. Additional service is also provided to Waipahu. The route provides service from these areas via routes along Fort Weaver Road, Farrington Highway, Kamehameha Highway and Dillingham Boulevard to major employment and shopping areas in Honolulu. Currently, three buses per hour are provided during the morning and evening peak hours to and from Honolulu.

TRAFFIC VOLUMES

Traffic counts are taken at various locations along Fort Weaver Road on a regular basis by the State of Hawaii Department of Transportation. The most recent counts which are available for this area were taken between April and November of 1984 and were obtained for use in this study. The data provided an indication of the magnitude of the average daily traffic volumes, and the morning and evening peak hour volumes at selected locations on Fort Weaver Road and on several of the street street approaches at Fort Weaver Road. Figures 2 and 3 illustrate the daily and peak hour volumes, respectively.

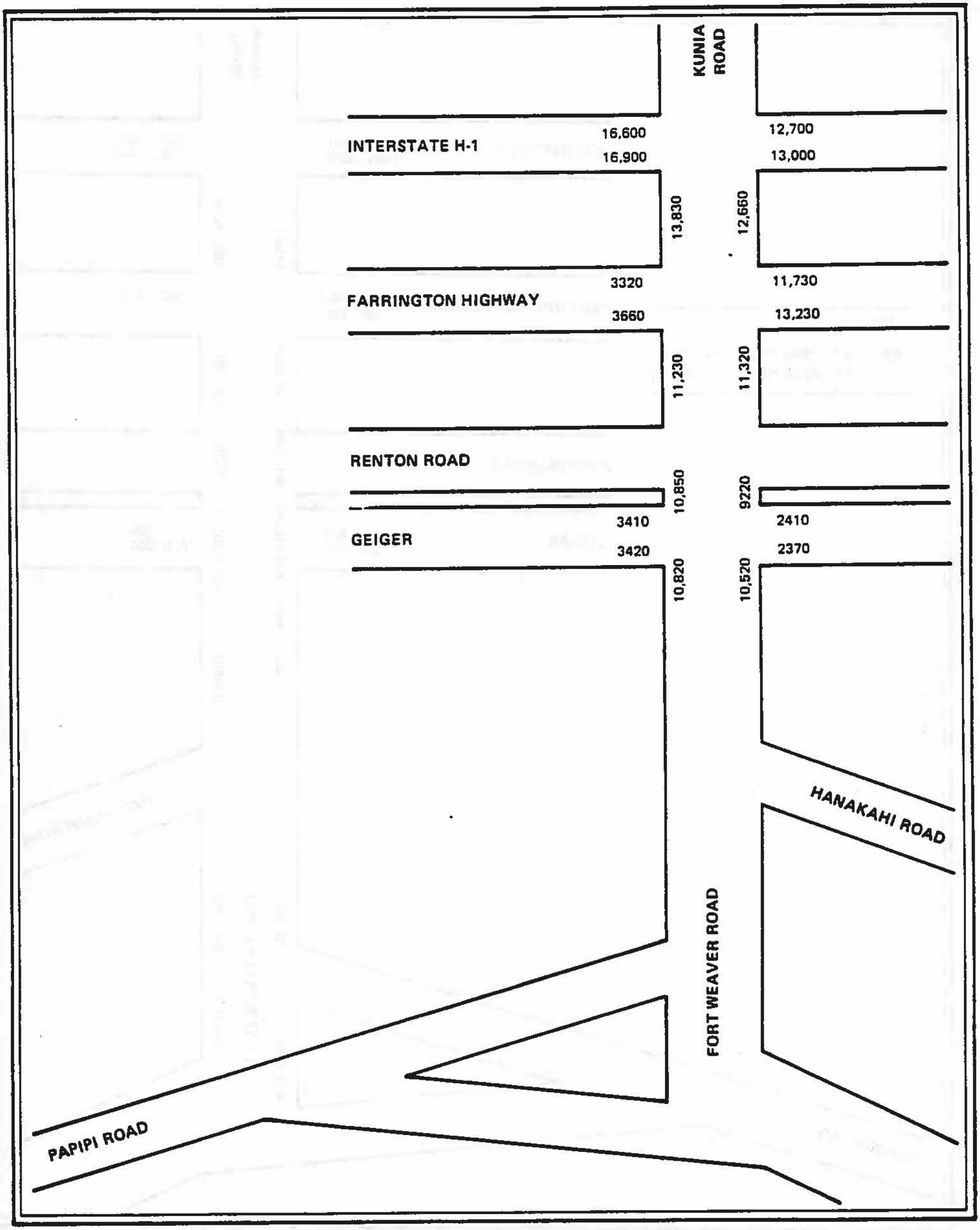

Figure 2
EXISTING TRAFFIC-ADT

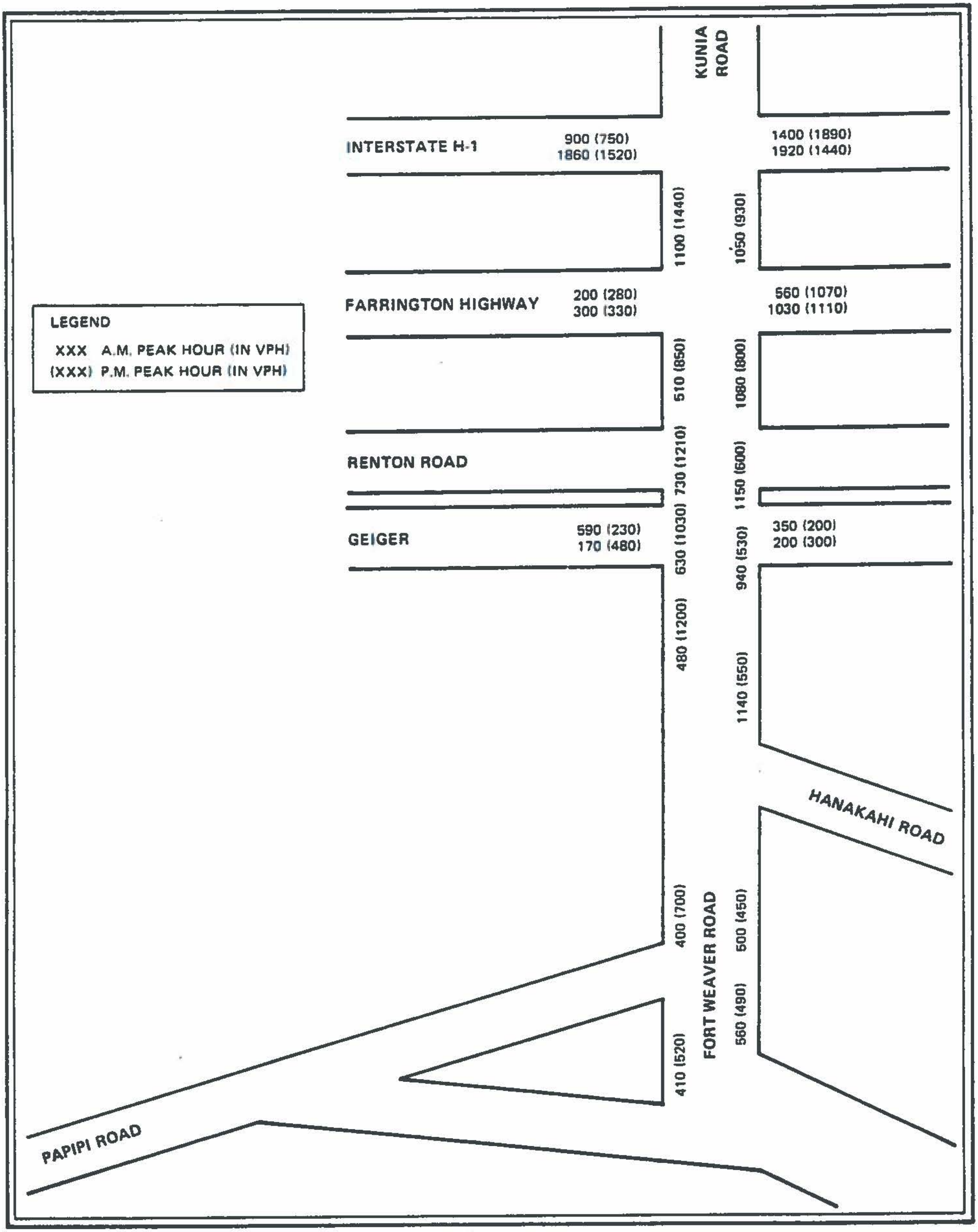

Figure 3
EXISTING TRAFFIC
PEAK HOUR

III. FUTURE CONDITIONS

In order to properly analyze the potential traffic impact of the Ewa Marina Community on the local and regional transportation system it was necessary to identify the future conditions which are expected to result after completion of the various elements of the project. One of the key issues which was addressed in the preparation of forecasts of future conditions was consideration of future transportation improvements which would affect the area, and the impact of additional growth and development resulting from other projects in the area. These three major issues were all considered in the assessment of future conditions and are reflected in the traffic projections used in this analysis.

PROPOSED DEVELOPMENT

The Ewa Marina Community is a marina subdivision development on 1,100 acres of land to be completed in two phases.

Phase I of the proposed Ewa Marina Community is estimated to be completed by 1995. At this stage the development would include the following uses on 733 acres of land:

* 4,850 multi-family dwelling units
* 55 acres of land for commercial use
* 27.5 acres of preservation area

The completion of Phase II is estimated to be beyond Year 2000. It would include the development of the remaining land and would include approximately 2,350 additional multi-family dwelling units.

The proposed widening and other improvements to Fort Weaver Road are sufficient to accommodate the future levels of traffic expected to be generated by the Phase I development. A second north-south roadway parallel to Fort Weaver Road will be necessary during the implementation of Phase II, or prior to the ultimate level of development in Ewa Marina. A monitoring program involving a traffic study every five years will be conducted to identify the specific timing of the implementation of this second north-south roadway.

The project is planned with an absorption rate which is relatively slow and spaced over a period covering up to ten years for Phase I. A conceptual description of the various parcels and land uses is indicated in Figure 4. As shown in the figure, proposed access to the development would be through two roadways intersecting Fort Weaver Road and two onto Papipi Road on the south. Increment 1 of the first phase is planned for completion over the first five years of the project with a proposed housing absorption schedule as follows:

Development Year	Units Absorbed	Population @ 3/D.U.
1	200 D.U.	600
2	300	900
3	350	1,050
4	300	900
5	140	570
Total	1,290 D.U.	3,870

FUTURE TRANSPORTATION IMPROVEMENTS

Proposed improvements to the transportation system in the project area include completion of Fort Weaver Road widening and expansion of the bus service to the area. The improvements are discussed below.

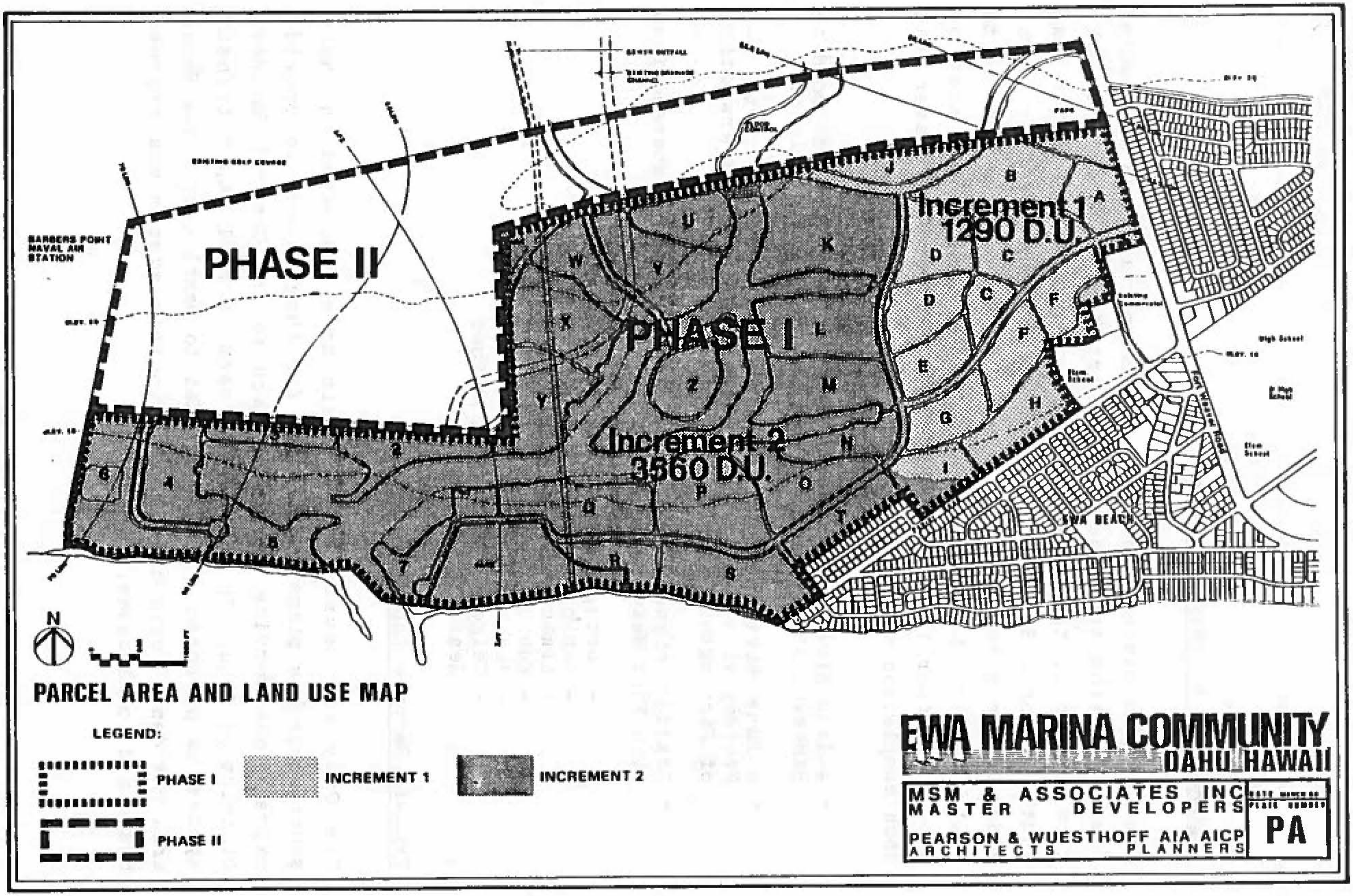

Figure 4
SITE PLAN

Highway and Roadway Improvements

The State of Hawaii Department of Transportation has scheduled for completion the widening of Fort Weaver Road from the termination of the existing four-lane roadway at Renton Road south to North Road in Ewa Beach. The next section to be widened, from Renton Road to Hanakahi Street, is expected to begin construction in late 1985 with the final section sometime after 1990. The characteristics of Fort Weaver Road upon completion would consist of the following:

* 4-lane divided highway striped median from North Road to Hanakahi Street with provisions for left-turn lanes.
* 4-lane divided highway from Hanakahi Street to the H-1 Freeway with a major interchange above the intersection of Farrington Highway with Kunia Road.
* Traffic signals at the following street intersections with Fort Weaver Road.
    - North Road
    - Papipi Road
    - Aikanaka Road
    - Kuhina Street
    - Hanakahi Street
    - Geiger/Iroquois Point Road
    - Renton Road

Transit Service Improvements

The City and County of Honolulu have indicated in their short-range bus plans a provision for three buses to provide express bus service from Ewa Beach to the Central Business District of Oahu. In the longer term, a rail rapid transit system is proposed from Hawaii Kai to Pearl City. Ewa Beach area residents would have access to this system via express buses and local buses.

FUTURE TRAFFIC CONDITIONS

Regional traffic demand forecasts have been prepared by the State Department of Transportation as part of the island-wide transportation planning process. The forecasts for Fort Weaver Road, which are illustrated in Figure 5, represent the Year 2000 travel demand forecasts which were used as the basis for many of the planned improvements in the area. It is important to recognize, however, that these figures represent general assumptions regarding the projected growth and development in the area. The travel demand forecasting models used by the D.O.T. are not designed to reflect detailed development plans for specific projects such as Ewa Marina or the planned Ewa Plantation to the north of the project site. Therefore, a traffic engineering procedure incorporating the concepts of trip generation, trip distribution, mode split and traffic assignment was used to estimate the incremental traffic generated by expected new development in the region. These incremental volumes were then added to those existing to provide projected peak hour traffic volumes. The basic premise is that new development would incrementally add to existing traffic volumes.

As part of the procedure, a scenario of future land uses which could reasonably be expected for Central and West Oahu was developed in consultation with cognizant agencies. A description of the anticipated land uses, the generation and distribution of trips, and the projected traffic volumes without the proposed Ewa Marina development follows.

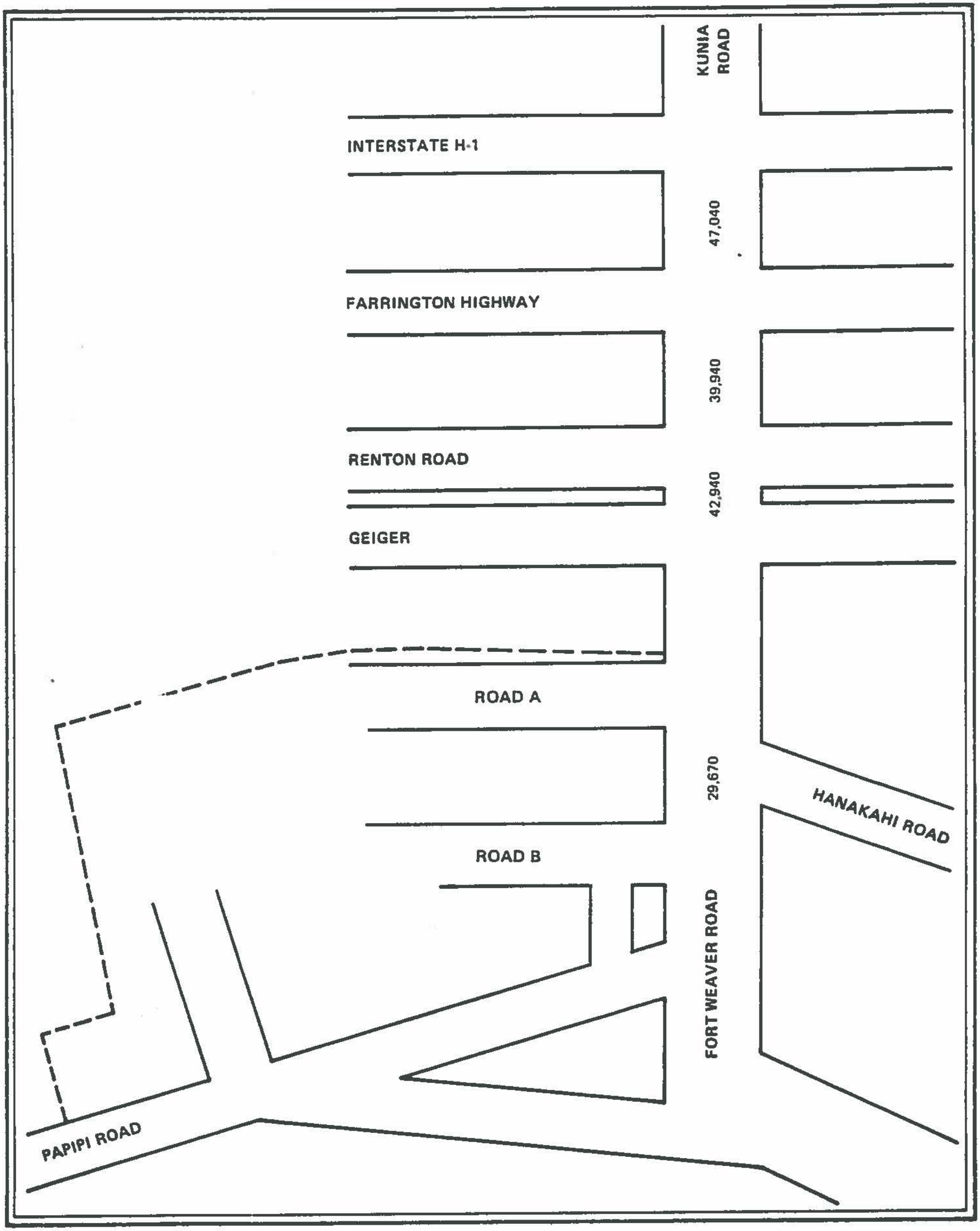

Figure 5
HALI 2000
FORECASTS-ADT

Land Use Forecasts

The first task was the development of reasonable land use forecasts for 1990, the projected completion date for Increment 1 of Phase I, and for 1995, the projected completion date for all of Phase I of the Ewa Marina Community. Residential development is expected to have the major impact upon traffic volumes in the area, with other land uses having relatively minor impact. A list of major residential developments which could be reasonably expected in the area by 1995 was based upon conversations with staff members of the U.S. Department of Housing and Urban Development (HUD), the City and County of Honolulu Department of General Planning (DGP), and private developers. In addition, estimates of general growth which can be expected for certain areas were also developed. The list is summarized in Table 1.

Development on Central and North Oahu is expected to have an impact upon the H-2/Kamahameha corridor, and the Waiawa Interchange, and was included in this study for this reason. Development on Leeward Oahu is expected to have an impact upon H-1, Farrington Highway, and the Waiawa Interchange. An additional 7,400 households are expected in the area between now and 1995, with much of the growth centered in Makakilo and Village Park.

In addition to residential development, the impact of the Campbell Industrial Park expansion, the new Barber's Point harbor, and a park was proposed for Leeward Oahu. The traffic projections for these projects were taken from previous studies.

Table 1

FORECAST OF MAJOR LAND USE CHANGES IN CENTRAL AND LEEWARD OAHU

(1985-1995)

Region	Additional Households
North Shore	1045
Wahiawa	0
Mililani	5000
Waianae Coast	1600
Makakilo	4000
Village Park	1750
Ewa Beach	350
Waipio-Gentry	1000[1]
Ewa Village	7000
West Beach	3000
Ewa Marina	4850

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[1]With 120 acres for a light industrial park.

Source: Conversations with staff members of HUD, DGP, and private developers.

Traffic Forecasts - 1995

The volumes and distribution of trips generated by the residential developments were estimated using procedures typically used in traffic engineering studies. Standard trip generation rates (as shown on Table 2) were used to forecast the number of trips generated during the AM and PM peak hour from each development. Assumptions were made regarding the proportion of single-family and multi-family units in each development. The total number of trips generated by each development is shown in Table 3.

Trip distribution percentages for each development were estimated using information from previous studies. The trips generated from each development were then distributed to the major areas of Oahu, using the percentages shown in Table 4.

Consideration was also given to internal trips and transit mode split which would reduce the volume of auto vehicle trips. The proportion of internal trips is dependent upon the size of development and the amount of nonresidential activity within the development. High transit patronage was expected for work trips made to Honolulu. Furthermore, the transit mode share decreased with increasing distance from the CBD. Mode shares ranged from ten percent for Mililani and Makakilo to zero percent in the North Shore.

The assignment of trips to the highway network is a straightforward method. The incremental traffic volumes from each development were then added to the existing traffic volumes to obtain the 1995 forecast year assignment.

The projected peak hour volumes along Fort Weaver Road and Kunia Road for 1995 without Ewa Marina are indicated in Figure 6.

Table 2

TRIP GENERATION FACTORS[1]

Land Use	Daily (vpd)	PEAK HOUR (vph) A.M. IN	A.M. OUT	P.M. IN	P.M. OUT
Residential (trips per dwelling unit)	10.0	0.3	0.6	0.7	0.4
Apartment - Low Density (trips per d.u.)	6.1	0.1	0.4	0.6	0.4
Apartment - Medium Density (trips per d.u.)	5.4	0.1	0.4	0.4	0.2
Light Industrial (trips per acre)	60.0	7.4	1.9	3.0	9.0
Commercial - Shopping (trips per 1,000 sq ft GLA)	60.4	---	---	2.6	2.9

[1]Institute of Transportation Engineers Informational Report, "Trip Generation," 1976.

Table 3

TRIP GENERATION CHARACTERISTICS

Development	AM Peak Hour In	AM Peak Hour Out	AM Peak Hour Total	PM Peak Hour In	PM Peak Hour Out	PM Peak Hour Total	Daily
North Shore	295	610	905	420	305	725	10,080
Mililani	810	2,310	3,120	2,000	1,160	3,160	36,200
Waianae Coast	420	900	1,320	640	450	1,090	14,840
Makakilo	1,185	2,390	3,575	1,600	1,190	2,790	39,780
Village Park	525	1,050	1,575	700	525	1,225	17,500
Ewa Beach	105	250	355	140	105	245	3,500
Campbell Industrial Park/Harbor[1]	1,240	80	1,320	290	740	1,030	9,400
Waipio Gentry	1,200	820	2,020	1,060	1,480	2,540	17,200
Ewa Village	700	2,800	3,500	4,200	2,800	7,000	42,700
West Beach	900	1,800	2,700	2,100	1,200	3,300	30,000
Total	7,380	13,010	20,390	13,150	9,945	23,105	221,140

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[1] AMV, "Analysis of Harbor Traffic Impact and Waterborne Systems Patronage, Hawaii Statewide Harbor System Plan," 1977.

Table 4

TRIP DISTRIBUTION PERCENTAGES

Development	Honolulu	Pearl City	Waipahu	Makakilo (MAJOR AREA)	Ewa Beach	Waianae Coast	Wahiawa/ Mililani
North Shore	30	5	7	3	3	2	50
Mililani	68	2	3	2	2	3	20
Waianae Coast	40	2	9	10	9	27	3
Makakilo	60	5	10	4	4	6	10
Village Park	60	5	10	4	4	6	10
Ewa Beach	53	5	10	7	15	2	8
Campbell Industrial Park Harbor	53	5	10	7	15	2	8
Waipio-Gentry	68	2	3	2	2	3	20
Ewa Village	53	5	10	7	15	2	8
West Beach	53	5	10	7	15	2	8

Sources

AMV, "A Traffic Study for the Gentry-Waipio Development," 1978.

AMV, "A Traffic Study Fort Weaver Road-Farrington Highway Intersection," July 1978.

AMV/PBQD, Unpublished person trip tables used for the TH3 environmental impact statement study.

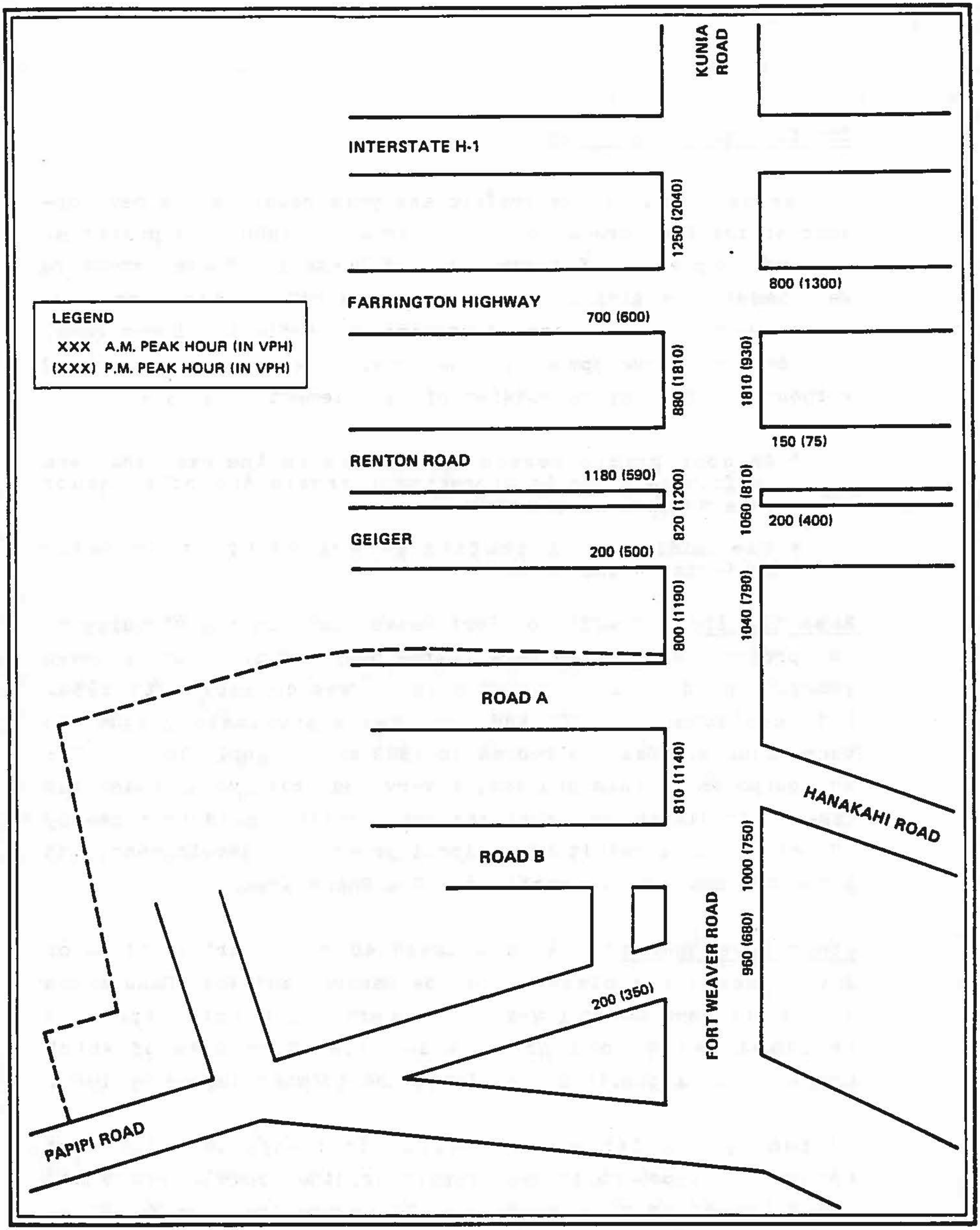

Figure 6
1995 FORECASTS WITHOUT PROJECT

Traffic Forecasts - 1990

The second part of the traffic analysis requires the development of traffic forecasts for the area for 1990, the projected date of completion of Increment 1 of Phase I. These forecasts were based on a similar analysis as described above for 1995 but with the appropriate adjustments to reflect a lower level of growth and development in the area. The forecasts for 1990 without the Ewa Marina consist of two elements. They are:

* An appropriate percentage growth in the existing base traffic as a result of regional growth and other minor developments in the area.
* The addition of traffic generated by other major projects in the area.

Base Traffic. Traffic on Fort Weaver Road in the vicinity of the project has changed very little over the past six or seven years. The data in Figures 2 and 3 was collected in 1984. Data collected in 1977 and 1981 was approximately equal to these counts. Data collected in 1983 was slightly lower. For the purposes of this project, a very conservative approach was taken. It was assumed that the base traffic would increase by 10 percent as a result of regional growth and development, and potential new changes within the Ewa Beach area.

Other Developments. As discussed above, a variety of major developments are planned for the Central and West Oahu areas during the next several years. No definitive information is available which can provide detailed forecasts of which projects may actually be completed and to what degree by 1990.

Currently available information indicates that the most appropriate approach to take regarding other developments and their impact on this study was to assume that the Ewa Plantation project, located north of Ewa Marina, would be the only project to consider. The others listed in Table 1 are too uncertain and/or too long range to include in this analysis; or the traffic expected to be generated by them would not impact Fort Weaver Road, the primary focus for this study. It was conservatively assumed that the Ewa Plantation would have developed 1750 dwelling units after Year 5 of Increment 1 for the Ewa Marina Community.

Figure 7 illustrates the projected future traffic in 1990 without the Ewa Marina-generated traffic. The volumes illustrated in this figure include both a 10 percent growth in existing traffic and the traffic expected to be generated by the Ewa Plantation.

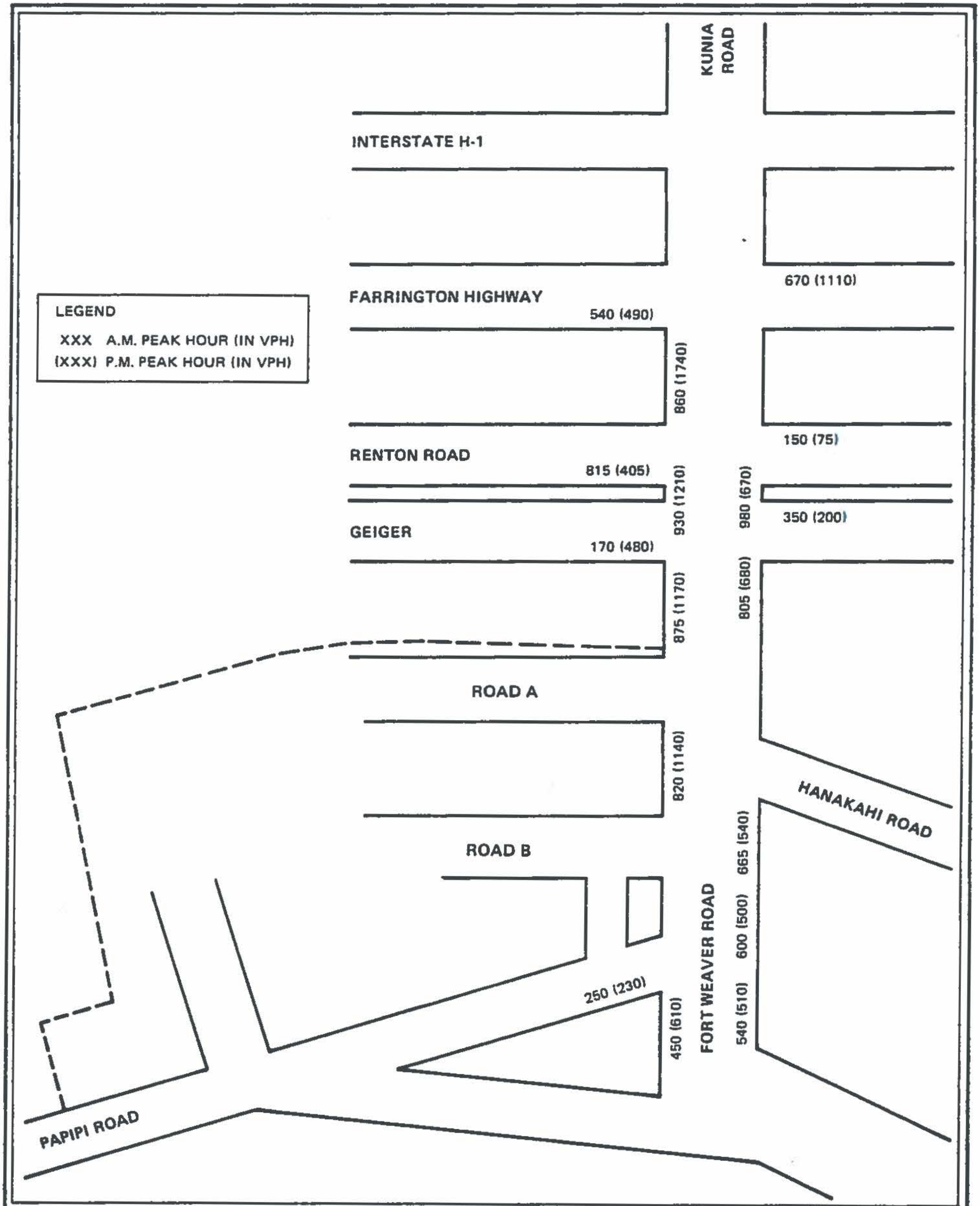

Figure 7
1990 FORECASTS WITHOUT PROJECT

IV. TRAFFIC IMPACT - INCREMENT 1

STUDY METHODOLOGY

The following section of the report describes the traffic impact of Increment 1 of Phase I of the proposed project on selected roadway facilities. The traffic impact of Increment 1 of the proposed project was determined by estimating the generation, distribution and assignment of the auto traffic from the project during the peak hours and adding it to the projected 1990 peak hour traffic volumes. The traffic impact of Increment 1 of the proposed Ewa Marina Community development was analyzed by comparing the total projected traffic volumes with the capacity of the planned transportation facilities. These volume-to-capacity ratios at selected facilities were developed using standard transportation engineering techniques.

DEVELOPMENT TRAFFIC

Before a traffic impact analysis could be conducted, it was necessary to determine the characteristics of the traffic which the project would be expected to generate. These characteristics include the total magnitude of the generated traffic, the hourly distribution of this traffic during the course of the day, the geographical distribution of the trips and the potential diversion to bus transit of these trips.

A careful analysis of the project and of traffic conditions which currently exist indicates that the most critical time periods relative to traffic impact would be the morning and evening peak periods on the adjacent streets and highways. These periods are not necessarily the peak period of traffic generation for specific land uses in the development; however, they are the periods during which the combination of projected and generated traffic by the development would have the highest volumes. The remainder of this section concentrates on these two time periods.

Traffic Generation

Traffic studies conducted in Honolulu and many mainland cities indicate that each specific land use has associated with it its own identifiable traffic-generating characteristics. These relate to the magnitude of the daily traffic, the peak periods of traffic generation, and the geographic distribution of attractions and productions. For a project such as the Ewa Marina Community, the following traffic generation rates can be applied.

* Daily - 6.1 trips/D.U.

* AM Peak - In - 0.1 trips/D.U.
  Out - 0.4 trips/D.U.

* PM Peak - In - 0.4 trips/D.U.
  Out - 0.2 trips/D.U.

Using these rates, it is estimated that Increment 1 of the proposed project would exhibit the following traffic generation characteristics:

* Daily - 7870 trips/day

* AM Peak - In - 130 trips/hour
  Out - 515 trips/hour

* PM Peak - In - 515 trips/hour
  Out - 260 trips/hour

The above information indicates that the 1,290 dwelling units projected for Increment 1 would generate 7,870 vehicle trips per day. Of these, 645 vehicles per hour are expected to occur during the morning peak hour and 775 vph during the evening peak hour.

Trip Distribution

The geographic distribution of the traffic which would be attracted or produced by the development is dependent upon various factors. These would include factors such as places of employment, school locations, shopping and commercial areas, dwelling units, and relative distances to these land uses. Based on the results of person trip tables which include the impact of the recently completed Hali 2000 estimates were made of the distribution of residential peak hour trips generated by the proposed development. The resulting trip distribution patterns are summarized in Table 5 as percentages. They represent the percentage of residential trips which would go to or come from each of the areas indicated. The table indicates that 85 percent of trips would have destinations north of the project site, while 15 percent would remain within Ewa Beach.

Table 5

TRIP DISTRIBUTION PERCENTAGES
FOR EWA MARINA

Major Area	Percentage
Honolulu	53%
Pearl City	5
Wahiawa/Mililani	8
Waipahu	10
Makakilo	7
Waianae Coast	2
Ewa Beach	15
TOTAL	100%

Traffic Assignment

The assignment of the generated traffic to the transportation facilities was relatively straightforward since the realigned and improved Fort Weaver Road would be the only major facility which traffic would need to utilize to gain access to the project from various areas north of the site. Access to areas internal to the site would be via two proposed roadways. All northern traffic to and from the site would utilize Fort Weaver Road and would disperse to areas north, east or west of the project via the various ramps at the present Kunia Interchange with H-1, Renton Road, Farrington Highway, and Kunia Road. The distribution of generated peak hour traffic as shown in Figure 8 was used in the analysis of potential impacts.

The State of Hawaii Department of Transportation has signed a contract to implement the next phase of the widening of Fort Weaver Road. The highway, which is currently widened to four

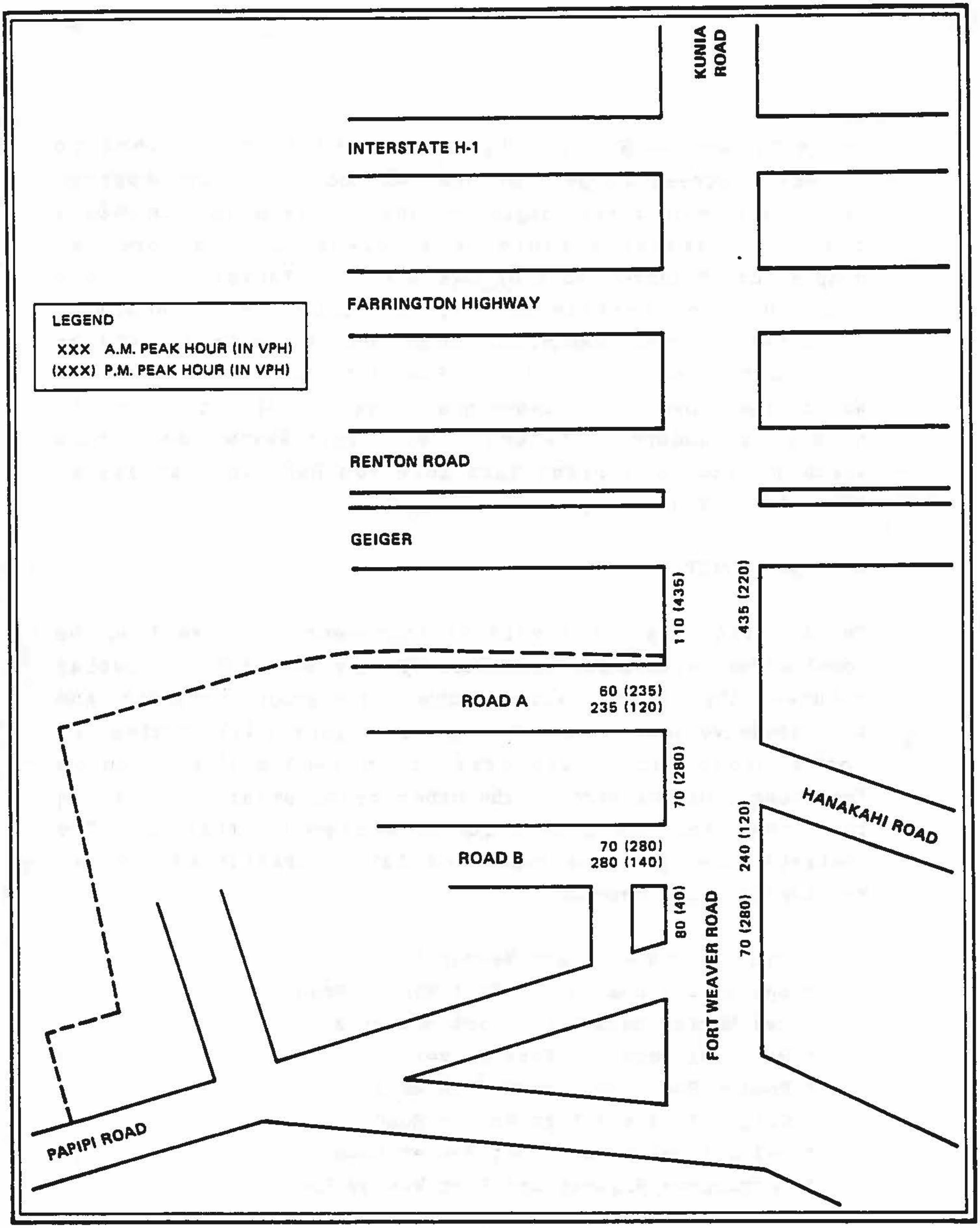

Figure 8
PROJECT TRAFFIC
INCREMENT 1

lanes to Renton Road, will be widened to four lanes to Hanakahi Street as part of the next construction program. Since this project will begin in 1986, it is highly probable that this widening would be completed long before the completion of Increment 1 of Ewa Marina. Therefore, it was felt that the traffic analysis for Increment 1 should be conducted under the assumption that Fort Weaver Road would be widened to four lanes south of Road A to Hanakahi Street. It would taper down to two lanes past Hanakahi Street but would have a southbound left-turn lane(on Fort Weaver Road) and a westbound exclusive right-turn lane (on Hanakahi Street) at the intersection.

TRAFFIC IMPACT

The traffic impact analysis of Increment 1, Phase I on the local street system was conducted by considering the existing volumes, the future volumes without the project traffic, and the future volumes with the project. Figure 9 illustrates the total projected future traffic in 1990 which includes Increment 1 of Ewa Marina, the other development projects in the area, and the growth in the background traffic. The analysis considered the impact of future traffic at several key locations. These are:

* Papipi Road and Fort Weaver Road
* Ewa Marina Road A and Fort Weaver Road
* Ewa Marina Road B and Fort Weaver Road
* Hanakahi Road and Fort Weaver Road
* Renton Road and Fort Weaver Road
* Geiger Road and Fort Weaver Road
* H-1 Interstate and Fort Weaver Road
* Farrington Highway and Fort Weaver Road

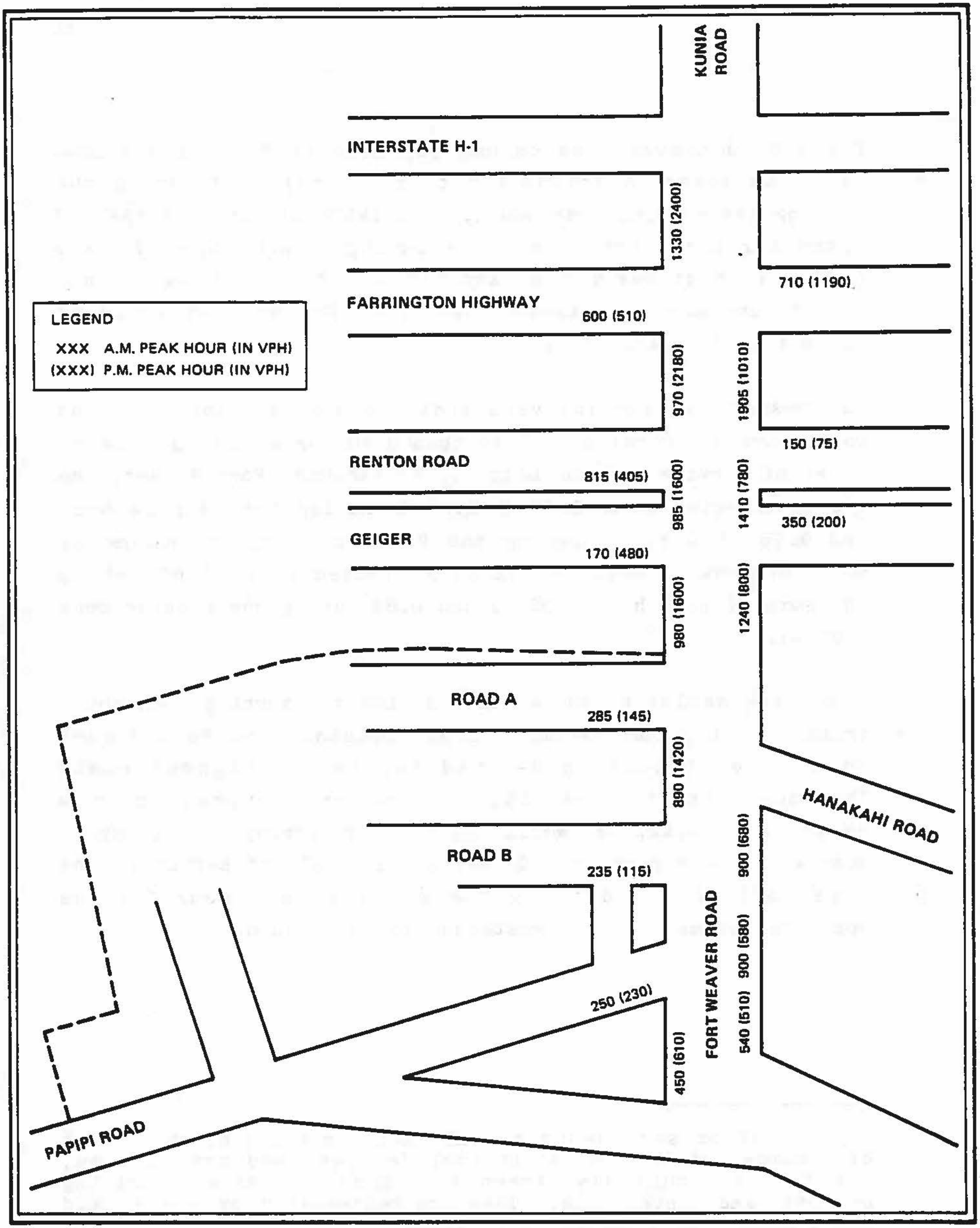

Figure 9
TOTAL 1990 TRAFFIC WITH PROJECT

Table 6 summarizes the volume/capacity (V/C) analysis conducted at these locations for traffic projected during the morning and evening peak hours. The table illustrates the V/C ratio for three conditions: existing conditions, future (1990) without Ewa Marina, and future (1990) with Ewa Marina. Both future scenarios assumed that Fort Weaver Road would be widened to Hanakahi Street.

The results of the analysis indicate that all intersections would have a V/C ratio of less than 0.80, or would operate at Level of Service C/D[1] or better. At Hanakahi/Fort Weaver, the V/C is expected to be 0.77 (L.O.S. C) during the AM peak hour and 0.75 (L.O.S. C) during the PM peak hour; and at Geiger Road/Fort Weaver Road the V/C is projected to be 0.63 during the morning peak hour (LOS B) and 0.66 during the evening peak (LOS B).

Also, the analysis assumes that during the morning peak hour, traffic making the movement from northbound on Fort Weaver Road to eastbound on H-1 and Farrington Highway would "balance" itself. That is, a volume proportional to the respective capacities would use H-1 and Farrington Highway so both would have similar V/C ratios and levels of service. The same would occur driving the evening peak hour for the opposite movement, i.e., westbound to southbound.

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[1]Level of service is a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort, and convenience. They are represented by a standard which goes from A (best) to F (worst).

Table 6

SUMMARY OF VOLUME/CAPACITY ANALYSIS
(Increment 1, Phase I)

	Volume/Capacity Ratio					
	Morning Peak			Evening Peak		
		Future (1990)***			Future (1990)***	
	Existing**	Without E.M.	With E.M.	Existing**	Without E.M.	With E.M.
Papipi/Fort Weaver	0.45	0.49	0.54	0.59	0.65	0.68
Road B/Fort Weaver	--	--	0.22	--	--	0.13
Road A/Fort Weaver	--	--	0.16	--	--	0.14
Hanakahi/Fort Weaver	0.72	0.54	0.77	0.61	0.49	0.75
Renton/Fort Weaver	0.43	0.69	0.78	0.44	0.67	0.80
Geiger/Fort Weaver	0.55	0.61	0.63	0.52	0.49	0.66
H-1/Fort Weaver						
On-Ramp to H-1 East	0.42	0.53	0.78*	0.30	0.38	0.39
On-Ramp to H-1 West	0.16	0.18	0.19	0.23	0.29	0.30
Off-Ramp from H-1 East	0.17	0.40	0.42	0.40	0.48	0.80*
Off-Ramp from H-1 West	0.35	0.38	0.40	0.21	0.24	0.26
Farrington/Fort Weaver						
NB to EB	--	0.89	0.78*	--	0.69	0.82
WB to NB	--	0.38	0.42	--	0.65	0.67
WB to SB	--	0.56	0.74	--	0.70	0.80*

*Adjustments in assignment made to balance movement.

**Assume Fort Weaver Road widened to Renton Road.

***Assume Fort Weaver Road widened to Hanakahi Street.

TRAFFIC LEVELS

An analysis was made to determine the relative levels of traffic which can be attributed to various sources at key locations along Fort Weaver Road. The analysis concentrated on the section of roadway on Fort Weaver Road south of Farrington Highway and at the intersection of Fort Weaver and Farrington. The table below illustrates the percentage contribution of traffic from three sources at the intersection during the morning and evening peaks, and the section of road south of the intersection on a daily basis.

	AM Peak	PM Peak	ADT
Ewa Marina	13%	12%	15%
Ewa Plantation	22%	21%	20%
Background Traffic	65%	67%	65%

It can be seen that the majority of the traffic is the "background traffic," the existing traffic and the growth that occurred to it as a result of regional development. In each case, the Ewa Marina contributed 15% or less of the traffic.

SIGNALIZATION

An additional highway improvement required as part of Increment 1 will be the signalization of the intersections of Road A and Road B with Fort Weaver Road. The details of the signal warrants used to justify their installation is provided in Chapter VIII, the discussion on the Master Plan of Roadways for Ewa Marina. The implementation schedule for these signal installations has been prepared in conjunction with the development schedule for Increment 1 which was previously described. The proposed schedule for the two signals is as follows:

	Signal Installation	
	Year	No. Units
Road A/Fort Weaver Road	5	1200
Road B/Fort Weaver Road	1	200

V. TRAFFIC IMPACT - PHASE I

The analysis of the potential traffic impact of the entire Phase I of development of the Ewa Marina Community was conducted similarly to the analysis of Increment 1. Forecasts were developed for traffic expected to be generated by the proposed project after completion of Phase I of development. As previously indicated, Phase I includes development of 4,850 dwelling units and about 55 acres of commercial area. The forecasts of future project traffic were added to forecasts of traffic in 1995 without the project. These total volumes were then compared to the capacity of the roadway facilities expected to exist by 1995 in the vicinity of the project site.

DEVELOPMENT TRAFFIC

The techniques described for the analysis of Increment 1 traffic generation were used to calculate Phase I traffic forecasts for this analysis. An additional element of the Phase I analysis concerns the addition of commercial activities planned for the site. A total of 55 acres are planned for the project. It is estimated that 231,000 square feet of commercial space will be developed with the project. Of this total, 40,000 square feet is planned for the area adjacent to the existing commercial facilities along Fort Weaver Road south of Road "B" of the project. The remaining 191,000 square feet is planned for the area on the western edge of the site.

One of the issues which affects the traffic impact analysis is the consideration of the potential interaction between the residential units within the development and the commercial activities planned on site. The magnitude of this interaction has a significant impact on the traffic analysis as described below.

Traffic Generation

For the study it was determined that the major trip-generating land uses during the morning and evening peak periods would be the residential and commercial land uses. For Phase I of the project, it was assumed that the project would consist of a total of 4,850 multi-family dwelling units and 231,000 square feet of commercial space. The trip generation rates described and used for the Increment 1 analysis can be used for the remainder of the residential units in Phase I. Separate trip generation rates for the commercial facilities along Fort Weaver Road and for the space further within the interior of the site were developed. The commercial space planned for the area adjacent to the existing retail activities along Fort Weaver Road are expected to be similar to the trip generating characteristics of the existing site. The commercial facilities on the western edge of the site are expected to be a lower density marina-oriented specialty area. The traffic generation rates to be used in the Phase I analysis are provided below:

Table 7

TRIP GENERATION RATES

(Phase I)

Land Use	Units	AM Peak Hr In	AM Peak Hr Out	PM Peak Hr In	PM Peak Hr Out	Daily
Residential	Trips/D.U.	0.1	0.4	0.4	0.2	6.1
Commercial	Trips/					
Retail	1000 sq ft	---	---	2.67	2.67	60.7
Specialty		---	---	2.26	2.26	40.7

Using the above rates, trip generation estimates were made for the total Phase I development. These are summarized below.

Table 8

TRIP GENERATION

(Phase I)

Land Use	AM Peak Hr In	AM Peak Hr Out	PM Peak Hr In	PM Peak Hr Out	Daily
Residential	485	1940	1940	970	29,590
Retail	---	---	110	110	2,430
Specialty	---	---	430	430	7,770
TOTAL	485	1940	2480	1510	39,790

Internal Trips. The nature of the various types of development and their respective traffic-generating characteristics is such that a percentage of the trips generated by the residential land use would be a duplication of trips generated by the commercial land uses. The magnitude of trips was estimated and eliminated from the calculation.

Transit Trips. The degree to which trips are diverted to the bus transit system is dependent upon many factors. These factors include the fare and level of service of the bus system, the cost of operating an automobile, the level of congestion of the street system, the income of the trip maker, and the trip purpose. Based on a review of present bus patronage and in consideration of proposed transit express service during peak periods, estimates were made of the diversion to transit for each trip, purpose of trips generated by the proposed project. These varied from 10 percent for work trips from dwelling units in the development to employment centers in Central Honolulu, to zero diversion of any shopping trips.

External Trips. These factors were used to determine the total number of trips into and out of the development of land use type and by time of day. The results are summarized in Table 9.

Table 9

TOTAL GENERATED TRIPS EXTERNAL TO PROJECT

(Phase I)

	Morning		Evening	
Land Use	In	Out	In	Out
Multi-Family Residential	485	1,745	1,540	740
Commercial	---	--	110	100
TOTAL	485	1,745	1,650	840

Trip Distribution

The trip distribution pattern described in the previous section as related to Increment 1 was also used for Phase I. The pattern was described in Table 5 and was used in the analysis of Phase I traffic external to the site. The trips within Ewa Beach were distributed in relation to the following distribution of employment in surrounding areas:

* 20 percent to the Pearl Harbor Naval Reservation
* 30 percent to areas along Ewa Beach
* 50 percent of areas within the Barbers Point Naval Air Station

It was assumed that all commercial shopping trips would remain within the Ewa Beach area and that they would be distributed in relation to the following distribution of existing dwelling units in Ewa Beach.

* 47 percent to the Pearl Harbor Naval Reservation
* 37 percent to areas along Ewa Beach itself
* 16 percent to areas within the Barbers Point Naval Air Station

These figures were used with the estimate of external trips to estimate the total number of trips to each area. The resulting distribution of project-generated traffic on the various facilities is shown in Figure 10.

Traffic Assignment

The assignment of the project-generated traffic to the transportation facilities was relatively straightforward since the

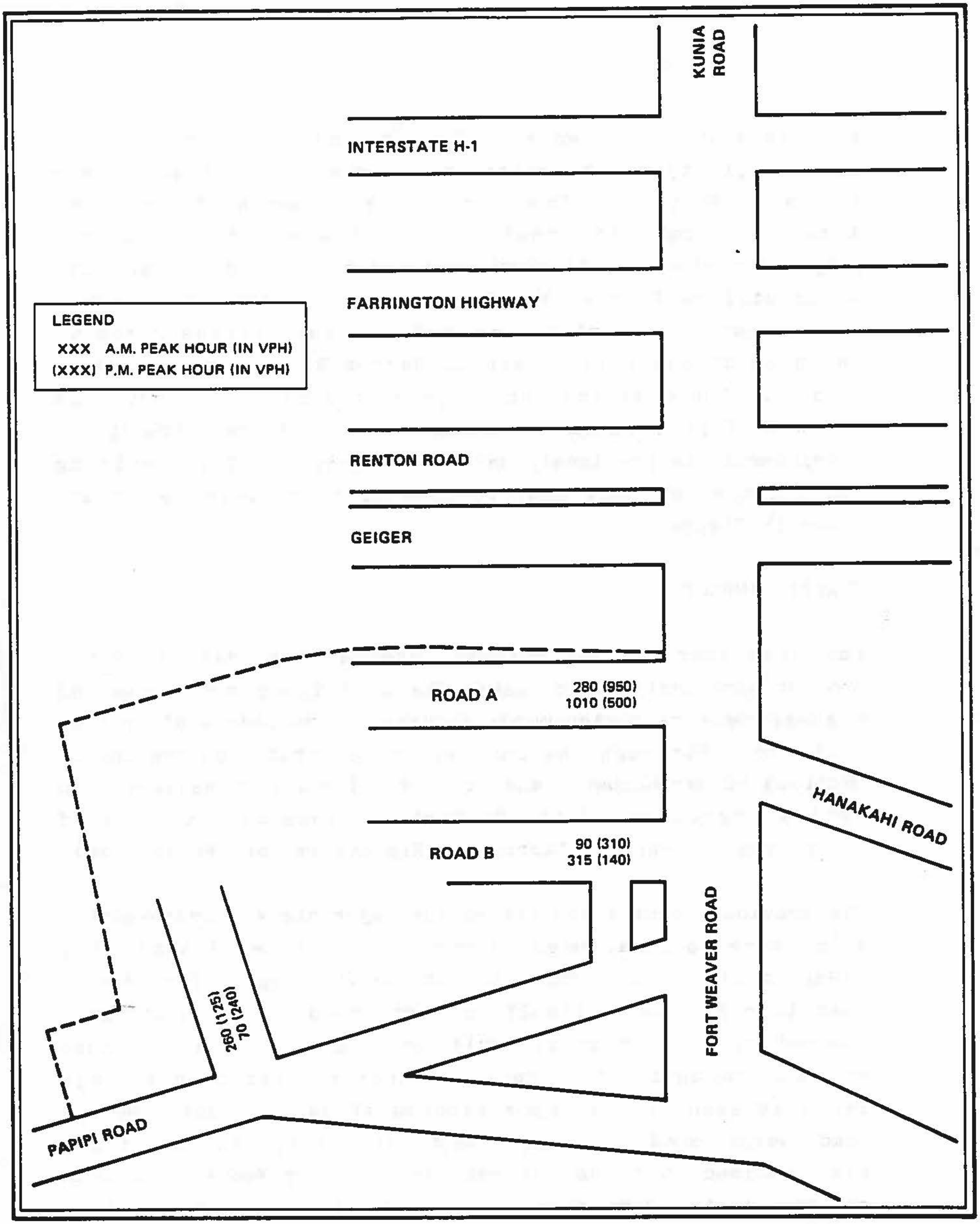

Figure 10
PROJECT TRAFFIC - PHASE I

realigned and improved Fort Weaver Road would be the only major facility which traffic would need to utilize to gain access to the project from various areas north of the site. Access to areas internal to the site would be via four proposed roadways. All northern traffic to and from the site would utilize Fort Weaver Road and would disperse to areas north, east or west of the project via the various ramps at the present Kunia Interchange, Renton Road, and Farrington Highway. The distribution of generated peak hour trips as shown in Figure 10 was added to those projected without the development, as previously shown in Figure 6. The resulting total projected peak hour volumes with the development are shown in Figure 11.

TRAFFIC IMPACT

The peak hour traffic volumes forecast for Phase I of the project were analyzed to assess the ability of the projected highway network to accommodate these future levels of traffic activity. Although the analysis concentrated on the intersections of key highways and streets, it was also necessary to review the capacity of the various ramps onto and off of Interstate H-1 and the Farrington Highway at Fort Weaver Road.

The previous chapter had listed the major highway improvements which were to be assumed as part of the Phase I analysis. These included the completion of the widening of Fort Weaver Road into Ewa Beach itself to North Road. It was further assumed that the highway would have signalized intersections and would be designed to include separate left-turn storage lanes at each of the major intersections, including Renton Road, Geiger Road, Hanakahi Street, and Papipi Road. It was also assumed that the intersection of Fort Weaver Road with the Ewa Marina Community internal Roads A and B would be

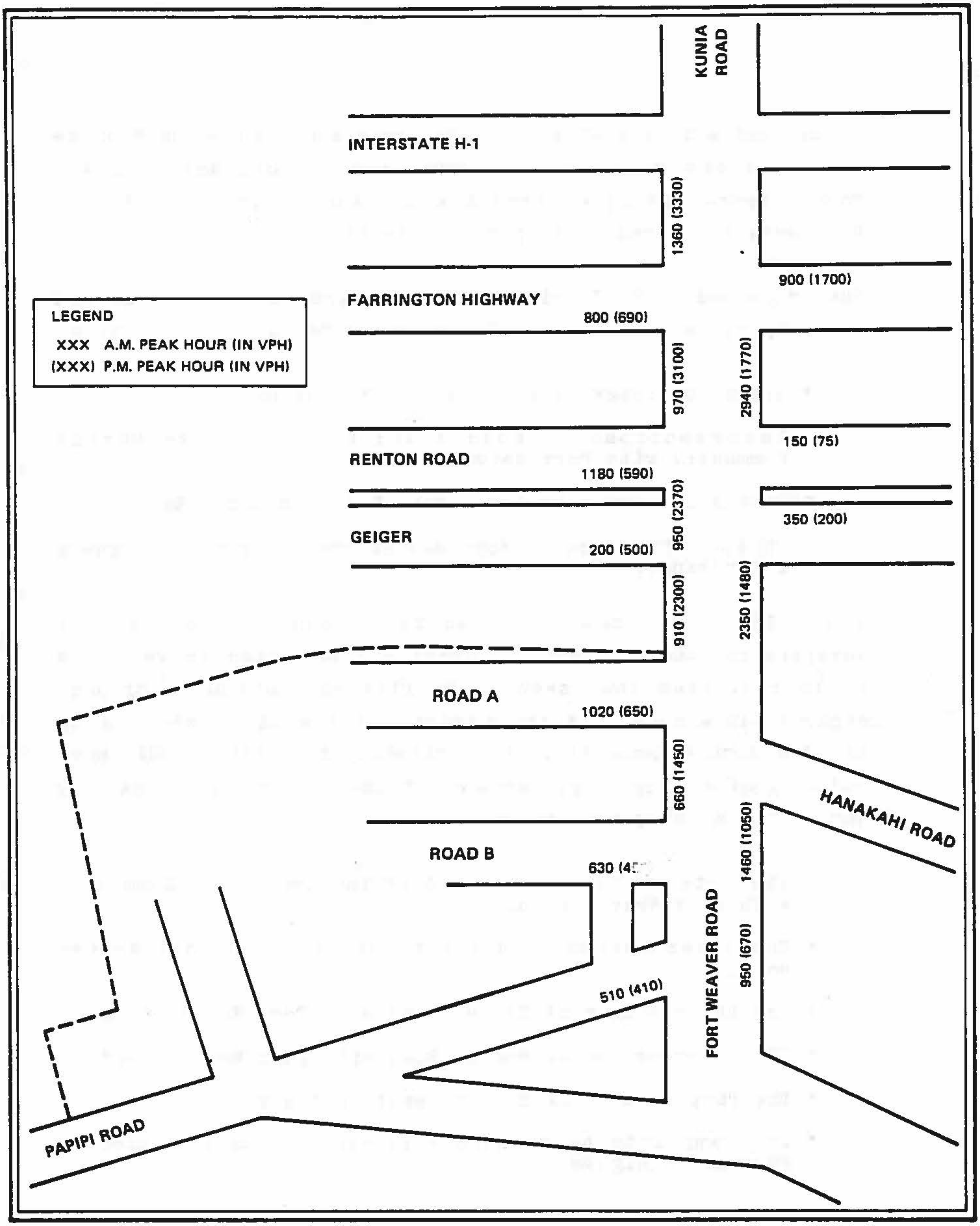

Figure 11
TOTAL 1995 TRAFFIC WITH PROJECT

signalized with left-turn storage lanes and right-turn storage lanes in the southbound approaches of Fort Weaver Road. Double left-turn lanes from Roads A and B onto Fort Weaver Road were also assumed as part of the highway plan.

The projected Phase I volumes were compared to the estimated capacity at each of the facilities described above, including:

* All major intersections on Fort Weaver Road.
* Intersections of Road A and Road B of Ewa Marina Community with Fort Weaver Road.
* On and off-ramps to Interstate H-1 from Kunia Road.
* On and off-ramps at Fort Weaver Road/Farrington Highway interchange.

Table 10 summarizes the results of the volume/capacity analysis for the critical facilities identified above. The table indicates that several facilities would be at or near capacity as a result of the additional traffic generated by the Ewa Marina Community. The following facilities would have volumes of at least 90 percent of the estimated capacity during the morning peak hour:

* The intersection of Road A of the Ewa Marina Community with Fort Weaver Road.
* The intersection of Hanakahi Street with Fort Weaver Road.
* The intersection of Geiger Road with Fort Weaver Road.
* The intersection of Renton Road with Fort Weaver Road.
* The ramp from Kunia Road to eastbound H-1.
* The ramp from northbound Fort Weaver Road to eastbound Farrington Highway.

Table 10

SUMMARY OF VOLUME-TO-CAPACITY ANALYSIS

(Phase I)

	Volume-to-Capacity Ratio					
	MORNING PEAK			EVENING PEAK		
		Development			Development	
Site	Existing	Without	With	Existing	Without	With
Papipi/Fort Weaver	0.46	0.53	0.63	0.64	0.70	0.73
Road B/Fort Weaver	(1)	(1)	0.75	(1)	(1)	0.48
Road A/Fort Weaver	(1)	(1)	0.93	(1)	(1)	0.82
Hanakahi/Fort Weaver	0.72	0.78	0.91	0.61	0.79	0.97
Geiger/Fort Weaver	0.55	0.72	0.90	0.52	0.73	0.98
Renton/Fort Weaver	0.43	0.85	0.97	0.44	0.89	0.99
Kunia Interchange						
On-Ramp to H-1 (east)	0.46	0.94	0.97	0.30	0.56	0.84
On-Ramp to H-1 (west)	0.15	0.58	0.69	0.23	0.52	0.57
Off-Ramp from H-1 (east)	0.17	0.51	0.55	0.39	0.47	0.97
Off-Ramp from H-1 (west)	0.33	0.44	0.66	0.21	0.54	0.63
Ramp from NB Fort Weaver to EB Farrington	(1)	0.35	0.99	(1)	0.40	0.47
Ramp from WB Farrington to NB Fort Weaver	(1)	0.65	0.33(2)	(1)	0.75	0.75
Ramp from WB Farrington to SB Fort Weaver	(1)	0.10	0.10	(1)	0.43	0.58

NOTE: Projected roadway conditions include realignment and improvement of Fort Weaver Road.

(1) Does not exist currently

(2) Assumes diversion of traffic from eastbound H-1 onto eastbound Farrington Highway.

During the evening peak hour, the following would be operating under these conditions:

* The intersection of Hanakahi Street and Fort Weaver Road.
* The intersection of Geiger Road and Fort Weaver Road.
* The intersection of Renton Road and Fort Weaver Road.
* The ramp from eastbound H-1 to Kunia Road.

This analysis indicates that although several locations are expected to operate at LOS E, the volumes at none of the locations is expected to exceed the projected capacity. This is true for either peak period. The traffic from the Ewa Marina Commmunity is expected to impact conditions at each location differently. At each of the intersections along Fort Weaver Road, it can be seen that the impact is relatively proportional to the volume of traffic the project is expected to generate in comparison to the volumes which are expected to exist without the project. This occurs because of the lack of any alternate routes which are available to Ewa Marina-generated traffic.

At other locations the impact is less because alternate routes are available. An especially significant fact is that the Ewa Marina adds only six percent to the total traffic on the ramp from Kunia Road onto eastbound Interstate H-1. This occurs because a significant volume of traffic is expected to be diverted onto Farrington Highway away from H-1 as a result of the development. This is a manifestation of a phenomenon resulting from the "leveling off" of traffic. The traffic volumes would divert to less congested facilities as congestion levels on the preferred facility increase. In actual conditions, the v/c ratios of parallel facilities, such as H-1 and Farrington Highway, normally are relatively equal. The figures have not been balanced in this analysis to reflect the relative attractiveness of the alternate routes. The H-1 is the preferred route but Farrington Highway will be used as the logical second choice.

Second North-South Roadway

The results of the analysis indicate that the future traffic volumes on Fort Weaver Road projected to occur by the completion of Phase I of the Ewa Marina community and the remainder of the other projects listed in Table 1 will not exceed the ultimate capacity of the highway. However, it is apparent that the magnitude of these volumes is sufficient to warrant serious consideration of a second north-south roadway which would mitigate the impact of the future growth. It should be recognized that the proposed developers of the Ewa Marina Community, M.S.M. & Associates, Inc., have agreed to a unilateral agreement with the City and County of Honolulu which addresses these issues directly. An excerpt from the agreement provides a description of the approach to be taken:

> "The above-described improvements shall be built as additional traffic loads are created by action of developer(s). The extent and timing of such improvements will be determined by traffic studies conducted by the developers in coordination with, and approved by, the City Department of Transportation Services and State Department of Transportation. Such studies shall be conducted every five (5) years from the effective date of this ordinance. The roadways will be designed and constructed in accordance with City standards for City roadways and State standard for Fort Weaver Road (including intersections).
>
> Costs for items a through c above shall be assessed to the developers involved in a manner determined by themselves and approved by the City and State."

It can be seen that although specific timetable is provided for the construction of this roadway, the timing for its completion is tied directly to a more tangible factor -- the actual traffic impact of future development on Fort Weaver Road.

VI. TRAFFIC IMPACT OF PHASE II

The second phase of the project involves the development of the additional 300 acres consisting primarily of 2,350 additional multi-family dwelling units. The analysis of its impact follows.

TRAFFIC GENERATION

The traffic generation rates used in the Phase I analysis were applied to the Phase II development plans to estimate the additional traffic volumes. Table 11 summarizes the traffic generation expected by the additional 2,350 dwelling units planned for Phase II. In a manner similar to the process used for Phase I, an estimate was made of the volume of internal traffic and travel expected to be completed by public transportation. The result was an estimate of the total projected traffic external to the project site. Table 12 summarizes these figures by land use and by time period.

The distribution factors used in the Phase I analysis were applied to the volumes in Table 12 to develop an estimate of the traffic distribution by cardinal direction. Table 13 summarizes this calculation.

The final step prior to traffic assignment was the determination of the diversion to the second north-south access road. The degree to which traffic would be diverted to this roadway was dependent on several issues, including the percentage distribution by cardinal direction, the projected level of service or degree of congestion on each roadway, the location of the dwelling units with respect to access to the two roadways, and relative travel times to H-1 via the two routes.

Table 11

TRAFFIC GENERATION - EWA MARINA COMMUNITY

(Phase II - 2,350 Dwelling Units)

Time Period	Rate	Total Traffic
Daily	6.1 trips/D.U.	14,330
AM Peak Hour		
IN	0.1 trips/D.U.	235
OUT	0.4 trips/D.U.	940
PM Peak Hour		
IN	0.4 trips/D.U.	940
OUT	0.2 trips/D.U.	470

Table 12

TOTAL GENERATED TRAFFIC EXTERNAL TO PROJECT

(Phases I and II)

	Vehicles Per Hour			
	AM Peak Hr		PM Peak Hr	
Land Use	In	Out	In	Out
Multi-Family				
Residential	690	2480	2310	1090
Retail	---	---	110	110
Specialty	---	---	430	430
TOTAL	690	2480	2850	1630

Table 13

DIRECTIONAL DISTRIBUTION OF GENERATED TRAFFIC

(Phases I and II)

	AM Peak Hour				PM Peak Hour			
	North	South	East	West	North	South	East	West
Multi-Family Residential								
IN	55	105	465	65	185	350	1565	210
OUT	200	375	1680	225	90	165	735	100
Retail								
IN	--	--	--	--	--	110	--	--
OUT	--	--	--	--	--	110	--	--
Specialty								
IN	--	--	--	--	50	230	100	50
OUT	--	--	--	--	50	230	100	50
TOTAL								
IN	55	105	465	65	235	690	1665	260
OUT	200	375	1680	225	140	505	835	150

The estimated assignment to each route is summarized in Table 14. The table indicates that although the majority of the traffic is expected to continue to use Fort Weaver Road, a significant percentage is projected to be diverted.

Table 14

ASSIGNMENT BY ROUTE FOR GENERATED TRAFFIC

(Phase I and II)

	Fort Weaver Road		Second North-South Access Road	
	IN	OUT	IN	OUT
AM Peak Hour				
North	30	100	25	100
South	--	--	--	--
East	280	1010	185	670
West	--	--	65	225
PM Peak Hour				
North	150	75	95	45
South	--	--	--	--
East	1110	510	730	325
West	--	--	250	140

TRAFFIC IMPACT

The projected volumes were added to the future volumes forecast for the area without Ewa Marina to determine the total future volumes after the completion of Phase II. These total future volumes were analyzed to assess the ability of the future roadway system to accommodate these volumes. The analysis assumed that the proposed widening of Fort Weaver Road previously described would be completed along with the addition of the second north-south access road from Ewa Marina to Farrington Highway and Interstate H-1. In order to provide a realistic assessment of the future volume/capacity condition, a general approach was used in the analysis. Although a volume/capacity analysis at the key intersections would provide a more detailed assessment of the potential impact, details of the second north/south roadway are not available prohibiting this type of analysis. The results of this more generalized analysis are provided below:

	V/C	LOS
Fort Weaver Road		
North Road to Hanakahi Street	0.85	D
Hanakahi to Renton Road	0.90	D/E
Renton Road to Farrington Hwy	0.90	D/E
Second North/South Access Roadway	0.65	B

It can be seen that the v/c ratios are all equal to or below 0.90 after the completion of Phase II. If the second north/south roadway is built, the potential impact of this future traffic would be less after Phase II as compared to Phase I traffic without the roadway.

VIII. MASTER PLAN OF ROADWAYS

The final element of work conducted for the Ewa Marina Community was the preparation of the master plan of internal roadways for the site. The master plan was developed to meet the needs generated by Phase I since it represents the ultimate level of development for the project for which there exists specific plans and a degree of certainty related to its implementation. The Phase I master plan includes roadway widths, intersection requirements in terms of geometric layout and operations, traffic control device requirements for key intersections, and a preliminary schedule of implementation for the traffic control devices at the intersections of Roads A and B with Fort Weaver Road.

TRAFFIC FORECASTS

The traffic generation projections previously described for Phase I and summarized in Table 8 were used as the basis for the development of the master plan. The project-generated traffic was assigned to the internal roadway system applying the external distribution pattern to the internal system. Two key elements of the distribution pattern were the specific internal roadways to be used to gain access to the external roadway system, and the proportion of trips which would remain within the site. Figure 12 illustrates the assignment of the Phase I project traffic to the internal roadway system.

ROADWAY REQUIREMENTS

The projected volumes illustrated in Figure 12 were used to develop roadway lane requirements for each of the major streets which were illustrated in Figure 4. The analysis was

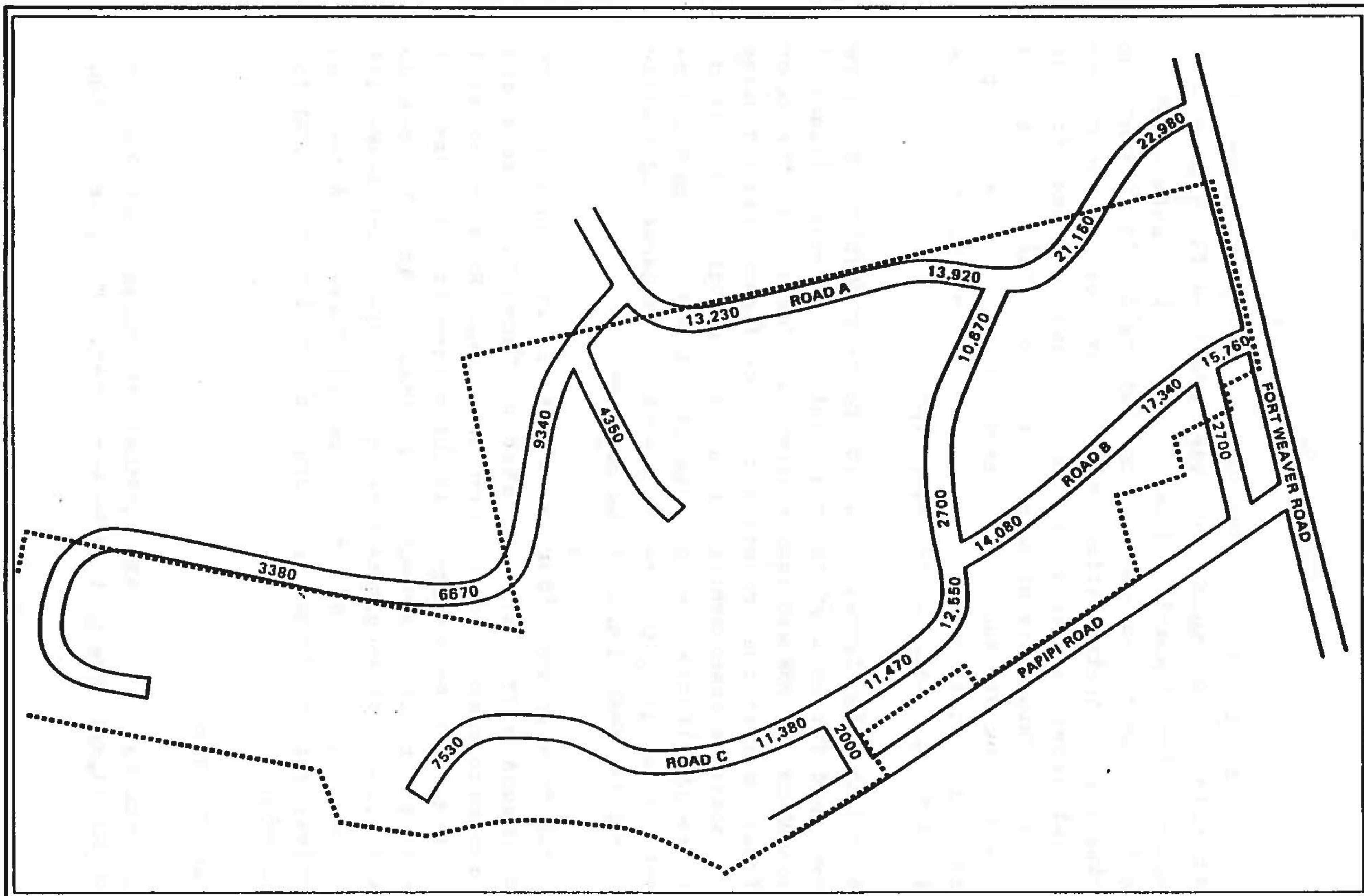

Figure 12
PHASE I - INTERNAL TRAFFIC PROJECTIONS
(ADT - 1995)

conducted using the average daily volumes as the means of determining the number of lanes required for each street segment. The standard used is illustrated in Figure 13 which indicates the roadway capacity for varying levels of operation using average daily traffic volumes. Level of Service C, the normal standard for residential areas, was used for the analysis. Using this standard, for example, indicates that a two-lane roadway would have a capacity of 15,000 vehicles per day. If left-turn lanes were added at intersections, the capacity would increase to 18,000 vpd.

Using data from Figures 12 and 13, roadway requirements were developed for each of the major internal streets. Figure 14 summarizes the roadway lane requirements for each of the major streets within the project site. The figure also indicates the locations where additional turn lanes would be required. Figure 15 illustrates the schematic details of these intersections including the traffic operations patterns and traffic control devices which could be required.

It can be seen that four lanes are required on Road A to accommodate traffic generated by Phase I. Road B can accommodate Phase I traffic with two lanes. However, it will be necessary to ensure that left-turn storage lanes are provided at all intersections to ensure that LOS C can be maintained. It should be noted that the left-turn lanes will not be needed until the later stages of Phase I. A two-lane roadway without these left-turn lanes will be sufficient for Increment 1.

TRAFFIC SIGNALS

The data in Figure 14 also indicate the three locations where traffic signals are felt to be warranted. The intersections

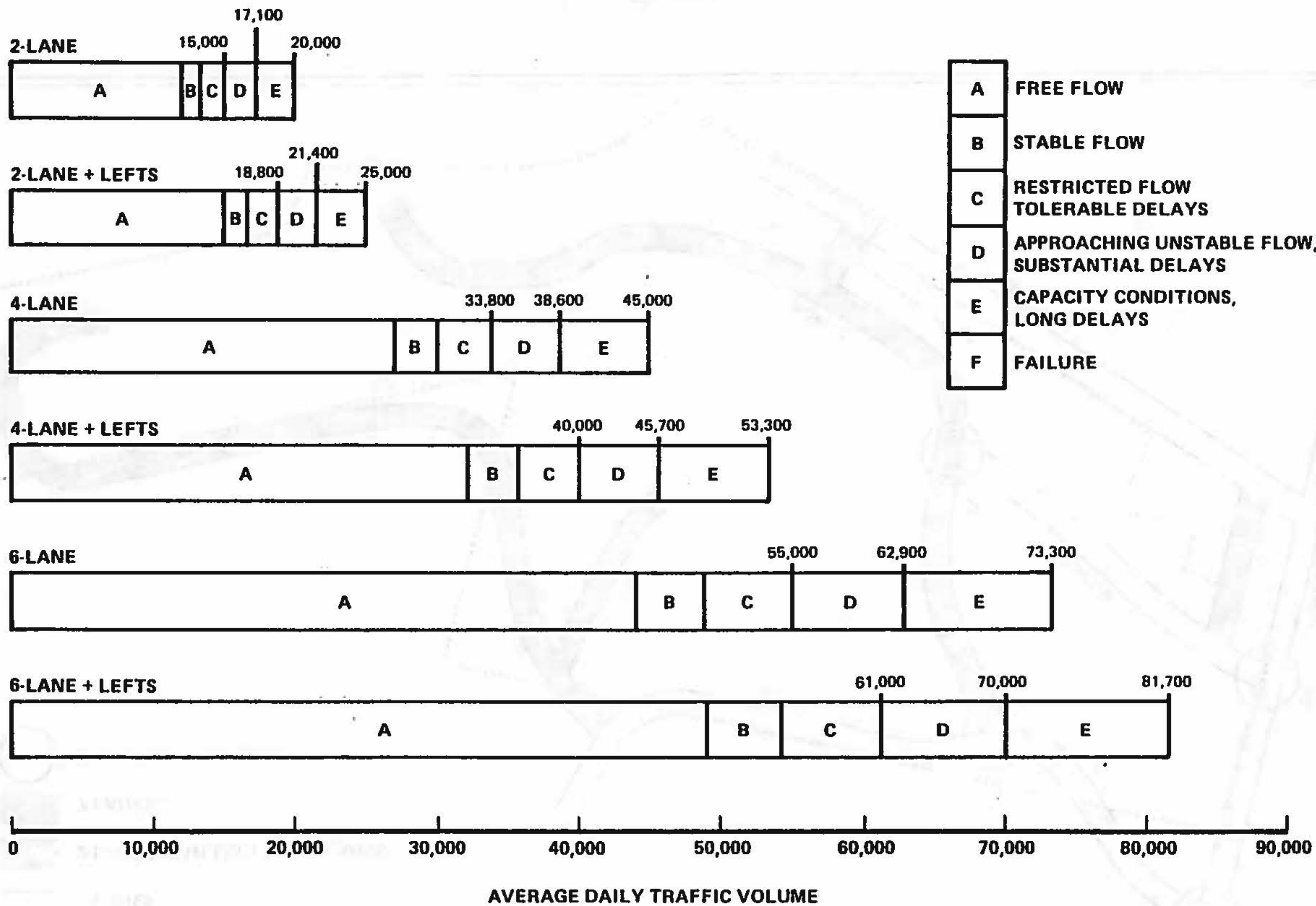

Figure 13
ROADWAY CAPACITY RANGES FOR VARYING
LEVELS OF OPERATION

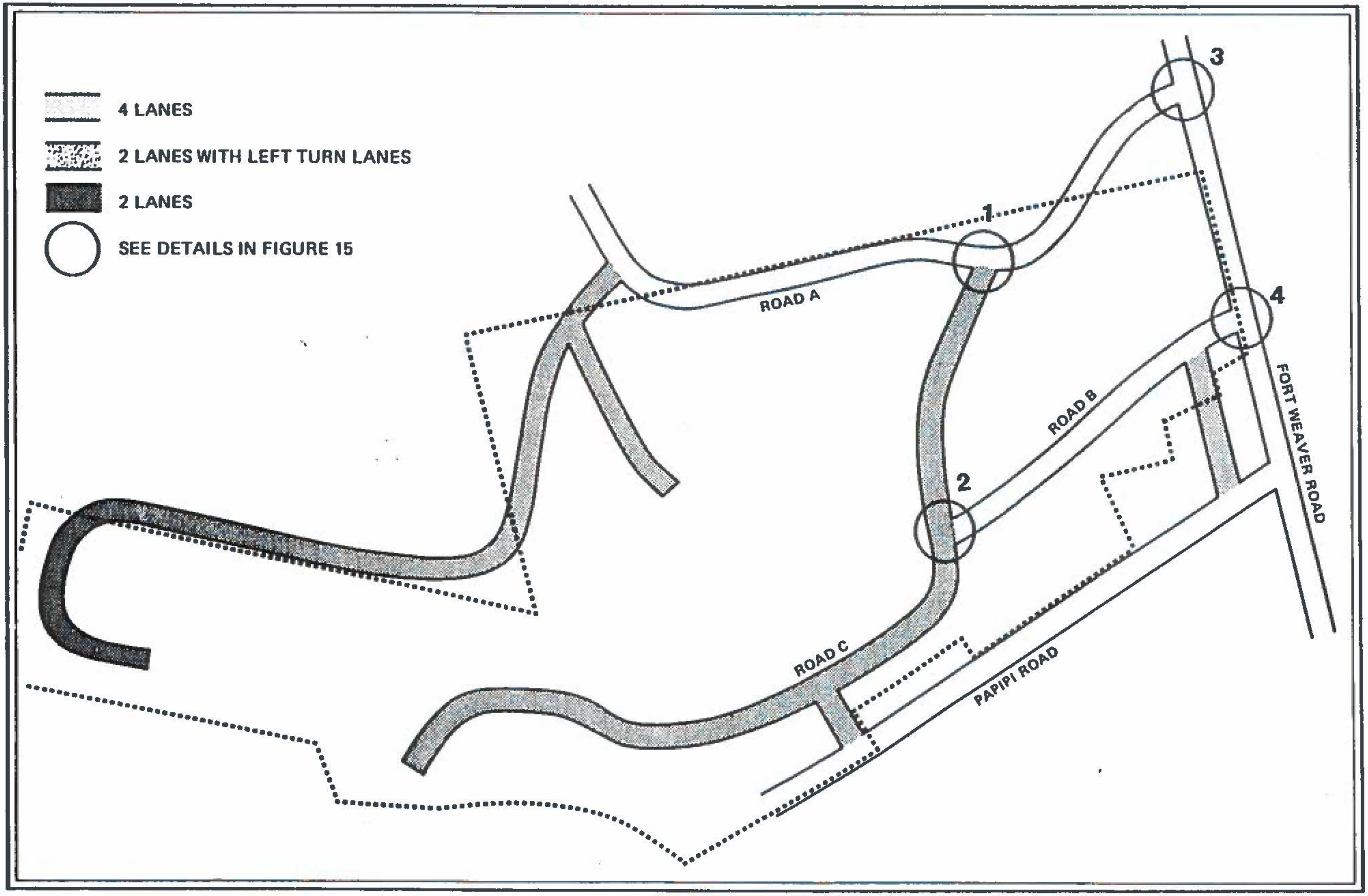

Figure 14
LANE REQUIREMENTS

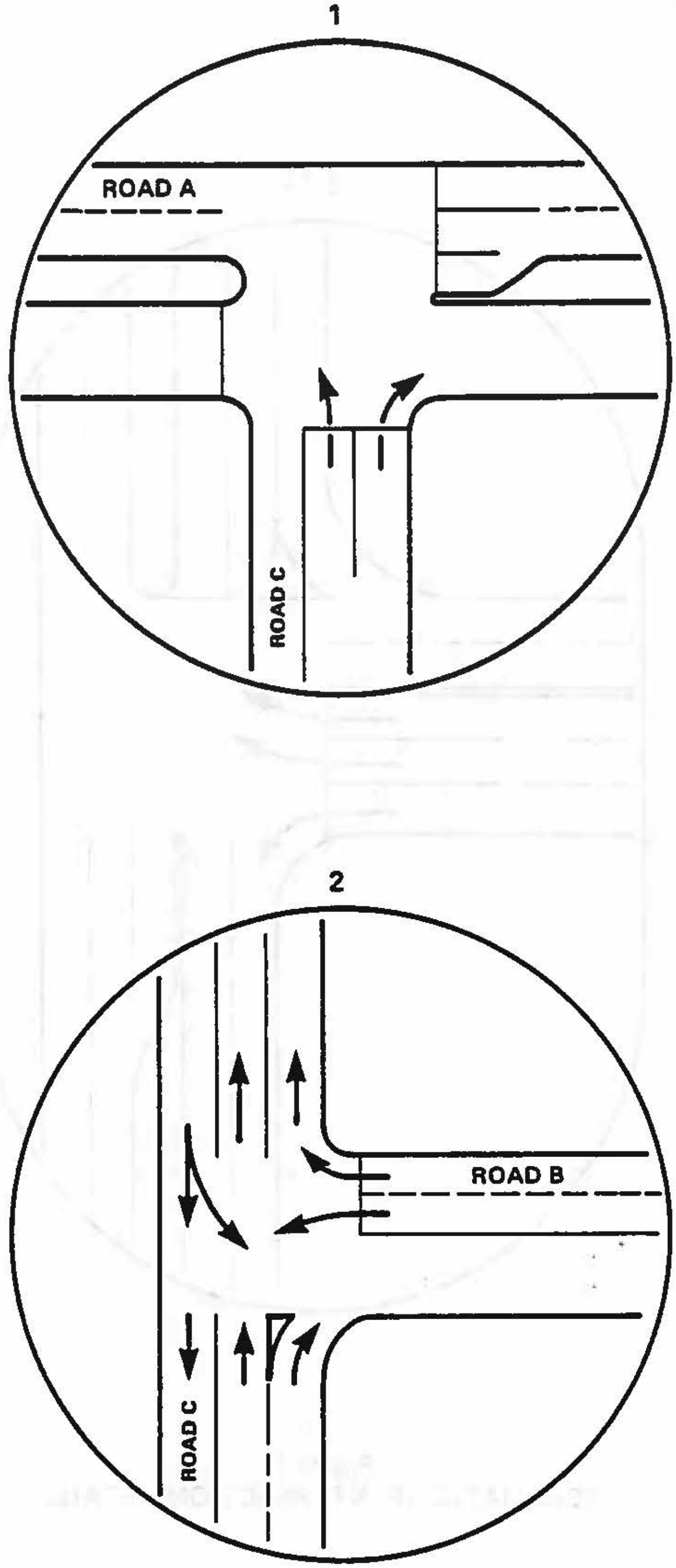

Figure 15
SCHEMATIC OF INTERSECTION DETAILS

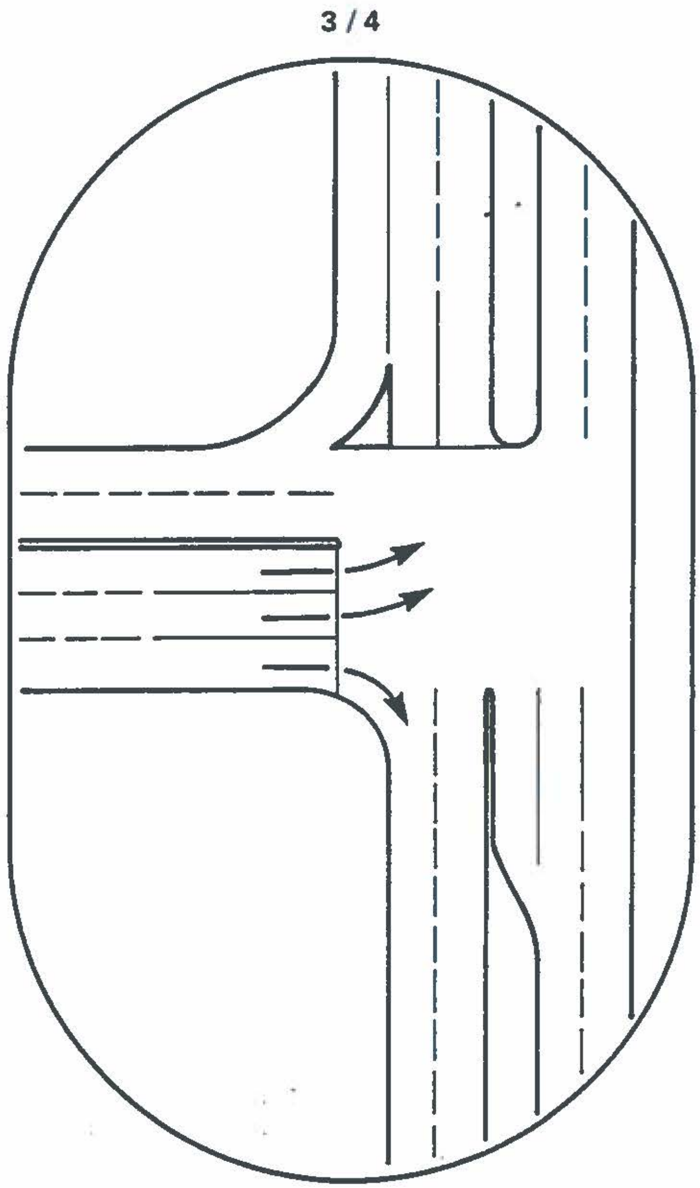

Figure 15
SCHEMATIC OF INTERSECTION DETAILS

of Road A and B with Fort Weaver Road and the intersection of Road A and Road C are the three locations. These signal requirements were based on warrants provided by the Uniform Code of Traffic Control Devices.

The two key traffic signal warrants which were used to identify locations where signals will be required were warrants 1 and 2. Warrant 1, the minimum vehicular volume warrant, is intended for application where the volume of intersection traffic is the principal reason for consideration of signal installation. The warrant is satisfied when, for each of any eight hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor-street approach to the intersection. An "average" day is defined as a weekday representing traffic volumes normally and repeatedly found at the location.

Number of Lanes for Moving Traffic on Each Approach: Major Street	Minor Street	VPH on Major Street (total of both approaches)	VPH on Higher Volume Minor-Street Approach (1 direction only)
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

Source: Manual on Uniform Traffic Control Devices, U.S. Department of Commerce, Bureau of Public Roads, U.S. Government Printing Office, Washington, D.C., 1961, p. 185.

Warrant 2, the Interruption of Continuous Traffic warrant, applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when, for each of any eight hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor-street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

Number of Lines for Moving Traffic on Each Approach: Major Street	Minor Street	VPH on Major Street (total of both approaches)	VPH on Higher Volume Minor-Street Approach (1 direction only)
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

Source: Manual on Uniform Traffic Control Devices, U.S. Department of Commerce, Bureau of Public Roads, U.S. Government Printing Office, Washington, D.C., 1961, p. 186.

Critical Volumes

It is recognized that the traffic volume projections indicated in the previous section are limited to total daily and peak hour volumes. To meet traffic signal warrant requirements, the eight highest hourly volumes are needed, therefore, it was necessary to develop information regarding the hourly variation of traffic over a 24-hour period on each of the streets. Figure 16 illustrates the percentage distribution of traffic for a typical street during the 16-hour period between 6:00 am and 10:00 pm. This data was used to identify the eight highest hourly volumes of traffic for each of the streets on the site.

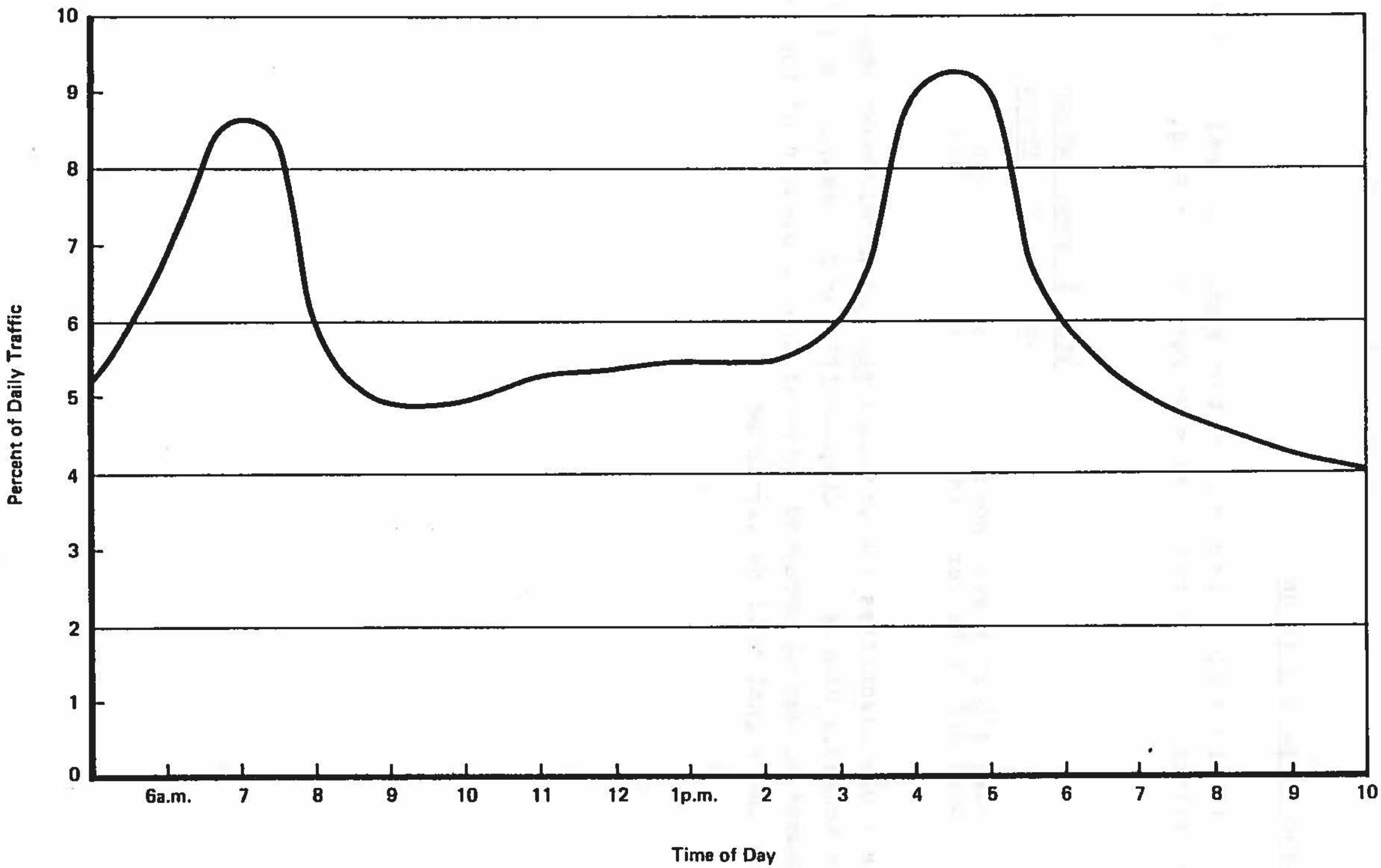

Figure 16
HOURLY VARIATION OF TRAFFIC

Signal Implementation

The table below indicates the proposed timing of the installation of the two signals on Fort Weaver Road.

	Signal Installation	
	Year	No. Units
Road A/Fort Weaver Road	5	1200
Road B/Fort Weaver Road	1	200

The table identifies the proposed year of development based on the schedule discussed in Chapter III for Increment 1 and the assumed number of occupied units at the completion of the year when the signal will be warranted.

STP

STP 8.1349

May 27, 1986

Mr. Roy L. Cox, Project Manager
M.S.M. and Associates, Inc.
33 South King Street, Room 410
Honolulu, Hawaii 96813

Dear Mr. Cox:

Final Traffic Study for the
Ewa Marina Community Project

Thank you for transmitting copies of the subject study and Mr. Dick Kaku's letter which responded to the several issues raised by our department.

We would also like to acknowledge that our meeting with you and your representatives including Mr. Kaku on February 28, 1986, was very fruitful and agree with your observation that our concerns were adequately discussed and covered.

Our major objective for the Ewa Marina project is the timely implementation of the necessary highway improvements. We concur with Mr. Kaku's statement that the extent and timing of the improvements required to accommodate project-generated traffic should be determined by traffic studies coordinated with and approved by the State DOT and City DTS. We further agree with Mr.Kaku's suggestion of modifying the time between traffic studies to two or three years, instead of five, to be more consistent with the project's actual traffic growth projections. We strongly recommend the developer responds positively to his suggestion and plan to conduct the required studies. This will assure that timely improvements can be implemented to avoid the deterioration of the highway level of service in critical areas.

We appreciate your coordinating this important matter with us.

Very truly yours,

Wayne J. Yamasaki
Director of Transportation

DT:ko

cc: DEP-E, HWY, HWY-PA, STP

D&M

M.S.M. & ASSOCIATES, INC.

July 1, 1986

Mr. Wayne J. Yamasaki
Director of Transportation
Department of Transportation
869 Punchbowl Street
Honolulu, Hawaii 96813

Dear Mr. Yamasaki:

Over the past several months we have held a number of meetings together with your staff and have exchanged several letters regarding the Traffic Study for the Ewa Marina Community Project.

In your letter dated May 27, 1986 you indicated that all items of concern have been adequately covered. Therefore, I am requesting that you approve the March 1986 "Traffic Study for Ewa Marina Community" prepared by Kaku & Associates together with Mr. Kaku's letter dated March 12, 1986, subject "Traffic Study for Ewa Marina Community" and your letter dated May 27, 1986, subject "Final Traffic Study for the Ewa Marina Community Project" as attachments to the Traffic Study.

As we have recommended on page 4 of Mr. Kaku's letter, MSM will, at MSM's expense, update the Ewa Marina Traffic Study at least every three years commencing three years following completion of the first residential unit.

I appreciate your cooperation with respect to this matter.

Sincerely,

Roy L. Cox

Roy L. Cox
Project Manager

RLC:jw

Attachments

cc: Ed Stevenson - Hawaii Pacific Eng.
Kay Muranaka - M&E Pacific

33 S KING STREET RM 410 • HONOLULU, HI 96813 • (808) 538-1593

KAKU ASSOCIATES
Transportation Planning, Traffic Engineering, Parking Studies

RECEIVED
MAR 25 1986
GACI, INC.

March 12, 1986

Mr. Roy Cox
MSM & Associates, Inc.
926 Bethel Avenue
Honolulu, Hawaii 96813

RE: Traffic Study for the Ewa Marina Community

Dear Roy:

As requested, we have finalized the traffic study for the Ewa Marina Community with the modifications which were discussed during my recent trip to Honolulu. Enclosed are 25 copies of the final report. The report includes a discussion of the potential impact of Increments 1 and 2 from Phase I of the project as well as the mitigation measures needed to address traffic issues which the proposed project could generate. The report also includes a review of the future highway needs for Phase II of the project. A final element of the report is the master plan of internal streets for the overall project including street widths, intersection layouts and traffic control devices.

We also recognize that the State of Hawaii Department of Transportation (DOT) has raised some issues in their review of the draft of the report. We have prepared responses to these comments from the DOT provided in their letter of November 19, 1985, a copy of which is attached. Their comments were directed at the draft version of the report prepared in September, 1985. The following can be related to the six comments from the DOT letter:

1. While the "Summary and Conclusions" section of the report does indicate that the Phase I plan for the Ewa Marina Community recommends double left-turn lanes at both Roads A and B, it also indicates that single lanes into and out of both access roads will be sufficient to accommodate the traffic volumes projected for Increment 1. The report indicates that the proposed widening of Fort Weaver Road to Hanakahi Road will provide sufficient roadway capacity to allow all intersections between Road B of Ewa Marina and H-1 to operate at LOS C or better through the completion of all 1290 dwelling unit planned in Increment 1, the 1990 timeframe. These include the following locations:

- o Road B and Fort Weaver Road
- o Road A and Fort Weaver Road
- o Hanakahi Street and Fort Weaver Road
- o Geiger Road and Fort Weaver Road
- o Renton Road and Fort Weaver Road
- o Ramps between Farrington Highway and Fort Weaver Road
- o Kunia interchange

The table on page 32 of the report indicates the projected V/C ratio at each of the key intersections on Fort Weaver Road under these conditions for morning and evening peak hours. All V/C ratios are 0.78 or better during the morning peak hour and 0.80 or better during the evening peak hour.

Since the construction contracts for this project have been let and the widening is projected to be completed by 1987, the incorporation of this improvement in the v/c calculations appears to be very reasonable and appropriate for Increment 1 which is scheduled for completion in 1990. Consequently, the results of the traffic analysis indicate that no other highway improvements beyond the widening of Fort Weaver Road to Hanakahi Road and the signalization of the Hanakahi/Fort Weaver intersection will be necessary to accommodate Increment 1, 1990, traffic volumes.

2. The purpose of the traffic study is to identify the projected highway needs under various future land use conditions as related to the development of the Ewa Marina Community. It is not intended to be a legal document or a description of the development agreement containing financing plans or programs for the project. As indicated in the DOT letter, the traffic study does indicate the future need for this highway at the completion of Phase I of the project. The study also indicates that the alignment of the proposed second north-south connector road should be illustrated to the edge of the property line so that it can be joined with any future development north of the Ewa Marina Community and be consistent with the master development plan of the Ewa Plain.

3. If Fort Weaver Road is widened to a six-lane facility, the projected operating conditions at the key intersections can be expected to improve. However, this improvement is not consistent with the overall highway plan for the area which assumes the highway to be a four-lane arterial and includes the addition of a second north-south roadway parallel to Fort Weaver Road.

4. The widening of Fort Weaver Road would have a positive impact at the various locations by providing additional capacity for the through movement on the highway. An additional improvement which could improve the operating conditions at the Kunia Interchange would be to widen the westbound off-ramp from H-1 to Kunia Road and the eastbound on-ramp from Kunia Road to H-1. Although both of these improvements would improve operating conditions on the ramps during both peak periods, neither is consistent with the overall highway plan for the area which includes the second north-south roadway.

5. We do not disagree with this concept or its objectives. However, as previously indicated, we do not feel that a technical traffic study can or should address this issue. This issue should be discussed as part of the overall development agreement between the owners/developers and the agencies with jurisdiction and responsibility for these matters. It should not be one of the criteria used to evaluate the technical quality of this analysis.

6. Double left-turn lanes at Road B are recommended as part of the overall master plan for Ewa Marina.

A final issue to be addressed is the basis for some information included in a letter from the State of Hawaii Department of Transportation to the Mr. John Whalen, Director of the Department of Land Utilization for the City and County of Honolulu on November 15, 1985, a copy of which is enclosed. The letter indicated that the second north-south roadway must be completed and in service when 3750 new dwelling units from Ewa Marina Community were completed.

Rather than establishing a relationship between a specific number of units and the completion of the second north-south roadway, a more practical and ultimately more useful approach would be to follow the guidelines established in the unilateral agreement between the City and County of Honolulu and M.S.M. & Associates which stated that the extent and timing of roadway improvements needed to accommodate project-generated traffic will be determined by traffic studies conducted by the developer in coordination with and, approved by, the City Department of Transportation Services and the State Department of Transportation. These studies would be conducted every five (5) years.

We recommend that references to number of units be deleted and that the guidelines of this agreement be used as the basis for binding the developer to the completion of necessary roadway improvements (e.g., the second north-south roadway) prior to receiving approval for the construction of additional units. One modification may be to reduce the time between traffic studies to two or three years to ensure that the timing of the improvements is consistent with the timing of the actual traffic growth.

It has been a pleasure conducting this study for you and assisting in the overall approval process. If you have any questions regarding any of the above or would like additional information, please call me.

Very truly yours,

Dick S. Kaku
Principal

Enclosures (3)